Final Report

An Assessment of Sea Scallop Abundance and Distribution in Open Access Areas: New York Bight and the Southern New England Area

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Project Summary

The sea scallop fishery is currently the most valuable single species fishery in the United States. Part of this success stems from a hybrid management strategy that incorporates both a spatial component (rotational closed areas) with traditional fishery management approaches. While much recent attention has focused on the success of closed areas (e.g. Elephant Trunk Closed Area), production from open areas had enabled scallop landings to remain high and increase over the past few years. Regardless of the management approach, experience tells us that the need to have good information on scallop distribution and biomass is critical to the effective management of the resource. This is true for both the rotational access areas and the areas open to general fishing under day-at-sea (DAS) control.

For the present study, we conducted fine scale surveys of the New York Bight (NYB) and Southern New England/Long Island (SNE) open access areas. Both of these areas represent important resources areas, yet are generally lightly surveyed by NMFS. The primary objective of this proposal was the determination of scallop distribution, abundance and biomass in the NYB and the SNE. In addition, we delineated the shoreward distribution of scallop abundance in shallow areas less than 40m but limited by the 13m depth contour, determined the relative performance of the NMFS survey dredge in areas with an abundance of sand dollars, identify areas of seed scallops, quantified yellowtail bycatch and provide additional information regarding the size selectivity and efficiency of the Coonamessett Farm Turtle Deflector Dredge (CFTDD) that is currently mandated for use in that area during some times of the year.

Results indicate that the scallop resource in both of the areas is healthy and we were able to delineate the shoreward extent of the scallop resource. Recruitment was observed in both surveys, with a more spatial extensive distribution of pre-recruits observed during the SNE survey. Gear performance analyses indicate that in the presence of large numbers of sand dollars, the efficiency of the NMFS survey dredge is diminished. This was especially the case during the NYB survey and is supported by both the results of the selectivity analyses and the large differences in the estimated biomass for two gears used in the survey.

Project Background

The sea scallop, *Placopecten magellanicus,* supports a fishery that in the 2010 fishing year landed 57 million pounds of meats with an ex-vessel value of over US $455 million (Lowther, 2011). These landings resulted in the sea scallop fishery being the most valuable single species fishery along the East Coast of the United States. While historically subject to extreme cycles of productivity, the fishery has benefited from recent management measures intended to bring stability and sustainability. These measures include: limiting the number of participants, total effort (days-at-sea), gear and crew restrictions and most recently, a strategy to improve yield by protecting scallops through rotational area closures.

Amendment #10 to the Sea Scallop Fishery Management Plan officially introduced the concept of area rotation to the fishery. This strategy seeks to increase the yield and reproductive potential of the sea scallop resource by identifying and protecting discrete areas of high densities of juvenile scallops from fishing mortality. By delaying capture, the rapid growth rate of scallops is exploited to realize substantial gains in yield over short time periods. In addition to the formal attempts found in Amendment #10 to manage discrete areas of scallops for improved yield, specific areas on Georges Bank are also subject to area closures. In 1994, 17,000 km^2 of bottom were closed to any fishing gears capable of capturing groundfish. This closure was an attempt to aid in the rebuilding of severely depleted species in the groundfish complex. Since scallop dredges are capable of capturing groundfish, scallopers were also excluded from these areas. Since 1999, however, limited access to the three closed areas on Georges Bank has been allowed to harvest the dense beds of scallops that have accumulated in the absence of fishing pressure.

In order to effectively regulate the fishery and carry out a robust rotational area management strategy, current and detailed information regarding the abundance and distribution of sea scallops is essential. Currently, abundance and distribution information gathered by surveys comes from a variety of sources. The annual NMFS sea scallop survey provides a comprehensive and synoptic view of the resource from Georges Bank to Virginia. In contrast to the NMFS survey that utilizes a dredge as the sampling gear, the resource is also surveyed optically. Researchers from the School for Marine Science and Technology (SMAST) and the Woods Hole Oceanographic Institute (WHOI) are able to enumerate sea scallop abundance and distribution from images taken by both a still camera and a towed camera system (Stokesbury, *et. al.,* 2004; Stokesbury, 2002). Prior to the utilization of the optical surveys and in addition to the annual information supplied by the NMFS annual survey, commercial vessels were contracted to perform surveys. Dredge surveys of the scallop access areas have been successfully completed by the cooperative involvement of industry, academic and governmental partners. The additional information provided by these surveys was vital in the determination of appropriate Total Allowable Catches (TAC) in the subsequent re-openings of the closed areas. This type of survey, using commercial fishing vessels, provides an excellent opportunity to gather required information and also involve stakeholders in the management of the resource.

With the exception of the annual synoptic surveys (NMFS, SMAST) most survey efforts have focused on the estimation biomass in a closed area prior to it's re-opening to harvest. Recently, the importance of an accurate estimate of scallop abundance in distribution in the open areas has become a priority. Over the last few years, open areas have accounted for a large and increasing percentage of overall landings, yet some areas of high effort are only lightly survey during the synoptic surveys. Given the importance of these open areas, it is critical to have accurate abundance and distribution information from these areas as well.

In addition to collecting data to assess the abundance and distribution of sea scallops in the SNE/LI and NYB areas, the operational characteristics of commercial scallop vessels allow for the simultaneous towing of two dredges. As in past surveys, we towed two dredges at each station. One dredge was a NMFS sea scallop survey dredge and the other was a CFTDD. This paired design allowed for the estimation of the size selective characteristics of CFTDD equipped with turtle excluder chains. Gear performance (i.e. size selectivity and relative efficiency) information is limited for this dredge design and understanding how this dredge impacts the scallop resource will be beneficial for two reasons. First, it will be an important consideration for the stock assessment for scallops in that it provides the size selectivity characteristics of the most recent gear configuration and second, this information will support the use of this gear configuration to sample closed areas prior to re-openings. In addition, selectivity analyses using the SELECT method provide insight to the relative efficiency of the two gears used in the study (Millar, 1992). The relative efficiency measure from this experiment can be used to refine existing absolute efficiency estimates for the New Bedford style scallop dredge and gain insight into the performance of the NMFS survey dredge.

A stated advantage of a sea scallop dredge survey is that one can access and sample the target species. One parameter routinely measured is the shell height:meat weight relationship. While this relationship is used to determine swept area biomass for the area surveyed at that time, it can also be used as an indicator of seasonal shifts in biomass due to the influence of spawning. For this reason, data on the shell height:meat weight relationship is routinely gathered by both the NMFS and VIMS scallop surveys. While this relationship may not be a direct indicator of animal health in and of itself, long term data sets may be useful in evaluating changing environmental conditions, food availability and density dependent interactions.

For this study, we pursued multiple objectives. The primary objective was to collect information to characterize the abundance and distribution of sea scallops within the SNE/LI and NYB areas. Utilizing the same catch data with a different analytical approach, we estimated the size selectivity characteristics of the commercial sea scallop dredge. In addition, a auxiliary component of the selectivity analysis allows for supplementary information regarding the efficiency of the commercial dredge relative to the NMFS survey dredge. As a third objective of this study, we collected biological samples to estimate a time and area specific shell height:meat weight relationship. Finally, finfish bycatch data includes information related to the incidence of yellowtail flounder, an important bycatch species for the scallop fishery.

Methods

Survey Area and Sampling Design

The SNE/LI and NYB areas were surveyed during the course of this project. The boundaries of the survey areas were delineated by both depth and fishery dependent information related to the spatial extent of the scallop population. Based on effort data from the fishery we were able to construct sampling domains that presumably fully encompassed the distribution of scallops in those broad geographic areas. We intentionally extended the shoreward boundary of both surveys to ensure that we would capture the inshore extent of the population. The inshore depth limit was 15 fathoms for both areas. Station maps with a polygon representing the sampling domains can be found in Figures 1 and 2. Sampling stations for this study were selected within the context of a systematic random grid. With the patchy distribution of sea scallops determined by some unknown combination of environmental gradients (i.e. latitude, depth, hydrographic features, etc.), a systematic selection of survey stations results in an even dispersion of samples across the entire sampling domain. The systematic grid design was successfully implemented during industry-based surveys since 1998.

The methodology to generate the systematic random grid entailed the decomposition of the domain (in this case a generated sampling domain) into smaller sampling cells. The dimensions of the sampling cells were primarily determined by a sample size analysis conducted using the catch data from survey trips conducted in the same areas during prior years. Since closed areas are of different dimensions and the total number of stations sampled per survey remains fairly constant, the distance between the stations varies. Generally, the distance between stations is roughly 3-4 nautical miles. In this case, because the domains were so large, the distance was larger at roughly 4-5 nm. Once the cell dimensions were set, a point within the most northwestern cell was randomly selected. This point served as the starting point and all of the other stations in the grid were based on its coordinates. The station locations for the 2011 SNE/LI and NYB surveys are shown in Figures 1 and 2.

Sampling Protocols

While at sea, the vessels simultaneously towed two dredges. A NMFS survey dredge, 8 feet in width equipped with 2-inch rings, 4-inch diamond twine top and a 1.5-inch diamond mesh liner was towed on one side of the vessel. On the other side of the vessel, a 15 foot CFTDD equipped with 4-inch rings, a 10-inch diamond mesh twine top and no liner was utilized. Turtle chains were used in configurations as dictated by the area surveyed and current regulations. In this paired design, it is assumed that the dredges cover a similar area of substrate and sample from the same population of scallops. The dredges were switched to opposite sides of the vessel mid-way throughout the trip to help minimize any bias.

For each survey tow, the dredges were fished for 15 minutes with a towing speed of approximately 3.8-4.0 kts. High-resolution navigational logging equipment was used to accurately determine and record vessel position. A Star-Oddi™ DST sensor was used on the dredge to measure and record dredge tilt angle as well as depth and temperature (Figure 3). With these measurements, the start and end of each tow was estimated. Synchronous time stamps on both the navigational log and DST sensor were used to estimate the linear distance for each tow. Histograms depicting the estimated linear distances covered per tow both surveys are shown in Figure 4.

Sampling of the catch was performed using the protocols established by DuPaul and Kirkley, 1995 and DuPaul *et. al.* 1989. For each survey tow, the entire scallop catch was placed in baskets. Depending on the total volume of the catch, a fraction of these baskets were measured for sea scallop length frequency. The shell height of each scallop in the sampled fraction was measured on NMFS sea scallop measuring boards in 5 mm intervals. This protocol allows for the estimation of the size frequency for the entire catch by expanding the catch at each shell height by the fraction of total number of baskets sampled. Finfish and invertebrate bycatch were quantified, with finfish being sorted by species and measured to the nearest 1 cm.

Additional samples were taken to determine area specific shell height-meat weight relationships. At roughly 25 randomly selected stations the shell height of 10 randomly selected scallops were measured to the nearest 0.1 mm. These scallops were then carefully shucked and the adductor muscle individually packaged and frozen at sea. Upon return, the adductor muscle was weighed to the nearest 0.1 gram. The relationship between shell height and meat weight was estimated using a generalized linear mixed model (gamma distribution, log link) incorporating depth as an explanatory variable using PROC GLIMMIX in SAS v. 9.2. The relationship was estimated with the following model:

$$\ln MW = \ln\alpha + \beta^{*}\ln SH + \gamma^{*}\ln Depth$$

where MW=meat weight (grams), SH=shell height (millimeters), Depth=depth (meters). α, β and γ are parameters to be estimated.

The standard data sheets used since the 1998 Georges Bank survey were used. Data recorded on the bridge log included GPS location, tow-time (break-set/haul-back), tow speed, water depth, catch, bearing, weather and comments relative to the quality of the tow. The deck log maintained by the scientific personnel recorded detailed catch information on scallops, finfish, invertebrates and trash.

Data Analysis

The catch and navigation data were used to estimate swept area biomass within the area surveyed. The methodology to estimate biomass is similar to that used in previous survey work by VIMS. In essence, we estimate a mean abundance from the point estimates and scale that value up to the entire area of the domain sampled. This calculation is given:

$$TotalBiomass = \sum_{j} \left(\frac{\left(\dfrac{CatchWtperTowinSubarea_{j}}{AreaSweptperTow} \right)}{Efficiency} \right) SubArea_{j}$$

Catch weight per tow of exploitable scallops was calculated from the raw catch data as an expanded size frequency distribution with an area and depth appropriate shell height-meat weight relationship applied (length-weight relationships were obtained from SARC 50 document as well as the actual relationship taken during the cruise) (NEFSC, 2010). Exploitable biomass, defined as that fraction of the population vulnerable to capture by the currently regulated commercial gear, was calculated using two approaches. The observed catch at length data from the NMFS survey dredge (assumed to be non-size selective) was adjusted based upon the size selectivity characteristics of the commercial gear (Yochum and DuPaul, 2008). The observed catch-at-length data from the commercial dredge was not adjusted due to the fact that these data already represent that fraction of the population that is subject to exploitation by the currently regulated commercial gear.

Utilizing the information obtained from the high resolution GPS, an estimate of area swept per tow was calculated. Throughout the cruise, the location of the ship was logged every three seconds. By determining the start and end of each tow based on the recorded times as delineated by the tilt sensor data, a survey tow can be represented by a series of consecutive coordinates (latitude, longitude). The linear distance of the tow is calculated by:

$$TowDist = \sum_{i=1}^{n} \sqrt{(long_2 - long_1)^2 + (lat_2 - lat_1)^2}$$

The linear distance of the tow is multiplied by the width of the gear (either 15 or 8 ft.) to result in an estimate of the area swept during a given survey tow.

The final two components of the estimation of biomass are constants and not determined from experimental data obtained on these cruises. Estimates of survey dredge gear efficiency have been calculated from a prior experiment using a comparison of optical and dredge catches (NEFSC, 2010). Based on this experiment, an efficiency value for the NMFS survey dredge of 38% was estimated for the rocky substrate areas on Georges Bank and a value of 44% was estimated for the smoother (sand, silt) substrates of some portions of Georges Bank and the entire mid-Atlantic. Estimates of commercial sea scallop dredge gear efficiency have been calculated from prior experiments using a variety of approaches (Gedamke *et. al.,* 2005, Gedamke *et. al.,* 2004, D. Hart, pers. comm.). The efficiency of the commercial dredge is generally considered to be higher and based on the prior work as well as the relative efficiency from the data generated from this study; an efficiency value of 65% was used for the SNE/LI and NYB areas. To scale the estimated mean scallop catch to the full domain, the total areas of the SNE/LI and NYB closed areas were calculated in ArcGIS v. 10.0.

Size Selectivity

The estimation of size selectivity of the CFTDD equipped with 4” rings, a 10” twine top and turtle chains was based on a comparative analysis of the catches from the two dredges used in the survey. For this analysis, the NMFS survey dredge is assumed to be non-selective (i.e. a scallop that enters the dredge is retained by the dredge). Catch at length from the selective gear (commercial dredge) was compared to the non-selective gear via the SELECT method (Millar, 1992). With this analytical approach, the selective properties (i.e. the length based probability of retention) of the commercial dredge were estimated. In addition to estimates of the length based probabilities of capture by the commercial dredge, the SELECT method characterizes a measure of relative fishing intensity. Assuming a known quantity of efficiency for one of the two gears (in this case the survey dredge at 44%), insight into the efficiency of the other gear (commercial dredge) can be attained.

Prior to analysis, all comparative tows were evaluated. Any tows that were deemed to have had problems during deployment or at any point during the tow (flipped, hangs, crossed towing wires, etc.) were removed from the analysis. In addition, tows where zero scallops were captured by both dredges were also removed from the analysis. The remaining tow pairs were then used to analyze the size selective properties of the commercial with the SELECT method.

The SELECT method has become the preferred method to analyze size-selectivity studies encompassing a wide array of fishing gears and experimental designs (Millar and Fryer, 1999). This analytical approach conditions the catch of the selective gear at length *l* to the total catch (from both the selective gear variant and small mesh control).

$$\Phi_c(l) = \frac{p_c r_c(l)}{p_c r_c(l) + (1 - p_c)}$$

Where r(l) is the probability of a fish at length l being retained by the gear given contact and p is the split parameter, (measure of relative efficiency). Traditionally selectivity curves have been described by the logistic function. This functional form has symmetric tails. In certain cases, other functional forms have been utilized to describe size selectivity of fishing gears. Examples of different functional forms include Richards, log-log and complimentary log-log. Model selection is determined by an examination of model deviance (the likelihood ratio statistic for model goodness of fit) as well as Akaike Information Criterion (AIC) (Xu and Millar, 1993, Sala, *et. al.*, 2008). For towed gears, however, the logistic function is the most common functional form observed in towed fishing gears. Given the logistic function:

$$r(l) = \left(\frac{\exp(a + bl)}{1 + \exp(a + bl)} \right)$$

by substitution:

$$\Phi(L)=\frac{pr(L)}{(1-p)+pr(L)}=\frac{p\frac{e^{a+bL}}{1+e^{a+bL}}}{(1-p)+p\frac{e^{a+bL}}{1+e^{a+bL}}}=\frac{pe^{a+bL}}{(1-p)+e^{ea+bL}}$$

Where *a*, *b*, and *p* are parameters estimated via maximum likelihood. Based on the parameter estimates, L_{50} and the selection range (SR) are calculated.

$$L_{50}=\frac{-a}{b} \qquad SR=\frac{2*\ln(3)}{b}$$

Where L_{50} defines the length at which an animal has a 50% probability of being retained, given contact with the gear and SR represents the difference between L_{75} and L_{25} which is a measure of the slope of the ascending portion of the logistic curve.

In situations where catch at length data from multiple comparative tows is pooled to estimate an average selectivity curve for the experiment, tow by tow variation is often ignored. Millar *et al.* (2004) developed an analytical technique to address this between-haul variation and incorporate that error into the standard error of the parameter estimates. Due to the inherently variable environment that characterizes the operation of fishing gears, replicate tows typically show high levels of between-haul variation. This variation manifests itself with respect to estimated selectivity curves for a given gear configuration (Fryer 1991, Millar *et. al.*, 2004). If not accounted for, this between-haul variation may result in an underestimate of the uncertainty surrounding estimated parameters increasing the probability of spurious statistical significance (Millar *et. al.,* 2004).

Approaches developed by Fryer (1991) and Millar *et. al.,* (2004) address the issue of between-haul variability. One approach formally models the between-haul variability using a hierarchical mixed effects model (Fryer 1991). This approach quantifies the variability in the selectivity parameters for each haul estimated individually and may be more appropriate for complex experimental designs or experiments involving more than one gear. For more straightforward experimental designs, or studies that involve a single gear, a more intuitive combined-haul approach may be more appropriate.

This combined-hauls approach characterizes and then calculates an overdispersion correction for the selectivity curve estimated from the catch data summed over all tows, which is identical to a curve calculated simultaneously to all individual tows. Given this identity, a replication estimate of between-haul variation (REP) can be calculated and used to evaluate how well the expected catch using the selectivity curve calculated from the combined hauls fits the observed catches for each individual haul (Millar *et. al.* 2004).

REP is calculated as the Pearson chi-square statistic for model goodness of fit divided by the degrees of freedom.

$$REP = \frac{Q}{d}$$

Where Q is equal to the Pearson chi-square statistic for model goodness of fit and d is equal to the degrees of freedom. The degrees of freedom are calculated as the number of terms in the summation, minus the number of estimated parameters. The calculated replicate estimate of between-haul variation was used to calculate observed levels of extra Poisson variation by multiplying the estimated standard errors by $\sqrt{REP}$. This correction is only performed when the data is not overdispersed (Millar, 1993).

A significant contribution of the SELECT model is the estimation of the split parameter which estimates the probability of an animal "choosing" one gear over another (Holst and Revill, 2009). This measure of relative efficiency, while not directly describing the size selectivity properties of the gear, is insightful relative to both the experimental design of the study as well as the characteristics of the gears used. A measure of relative efficiency (on the observational scale) can be calculated in instances where the sampling intensity is unequal. In this case, the sampling intensity is unequal due to differences in dredge width. Relative efficiency can be computed for each individual trip (Park *et. al.*, 2007).

$$RE = \frac{p/(1-p)}{p_0/(1-p_0)}$$

Where p is equal to the observed (estimated p value) and p_0 represents the expected value of the split parameter based upon the dredge widths in the study. For this study, a 15 ft. commercial dredge was used with expected split parameter of 0.6521. The computed relative efficiency values were then used to scale the estimate of the NMFS survey dredge efficiency obtained from the optical comparisons (44%). Computing efficiency for the estimated p value from Yochum and DuPaul (2008) yields a commercial dredge efficiency of 64%. That work was conducted throughout the range of the scallop in areas (Georges Bank) where dredge efficiency is expected to be lower. Preliminary observations suggest a slightly higher relative efficiency of the CFTDD relative to the standard New Bedford style scallop dredge. This selectivity analysis will provide an additional piece of evidence related to the efficiency of the CFTDD.

Preliminary analysis of data obtained on prior scallop surveys indicates that the NMFS survey dredge performs poorly when filled with sand dollars. The dredge bag appears to form a ball which lifts the bail and cutting bar off the bottom resulting in poor scallop catches relative to the commercial dredge. This characteristic of the survey dredge may result in an underestimate of scallop abundance in a given area. By examining the estimated selectivity parameters (L_{50}, SR and *p*) values with respect to concurrent sand dollar catch we were able to depict trends in those relationships and demonstrate the extent at which the performance of the dredges are affected. This was accomplished by individually fitting tows that had sufficient scallops to provide realistic selectivity parameters and then regress those parameters against an estimate of survey dredge fullness with sand dollars.

Results

Abundance and distribution

The survey cruises to the SNE/LI and NYB areas were completed in June and August of 2011, respectively. Summary statistics for the cruises are shown in Table 1. Length frequency distributions for the scallops captured during the SNE/LI and NYB surveys are shown in Figures 5 and 6. Maps depicting the spatial distribution of the catches of pre-recruit (<70 mm shell height), and fully recruited (≥70mm shell height) scallops from both the commercial and survey dredges are shown in Figures 7-14. Mean total and mean exploitable scallop densities for both the survey and commercial dredges are shown in Table 2. This information expanded to the area of the entire SNE/LI and NYB closed areas and representing an estimate of the total number of animals in the area is shown in Table 3. The mean estimated scallop meats weight for both the commercial and survey dredges for both of the shell height:meat weight relationships used is shown in Table 4. Mean catch (in grams of scallop meat) for the two dredge configurations as well as the two shell height: meat weight relationships are shown in Table 5. Total and exploitable biomass for both shell height:meat weight relationships and levels of assumed gear efficiency are shown in Tables 6 and 7 (total biomass is not estimated due to the selective properties of the commercial gear). Shell height-meat weight relationships were generated for the area. The resulting parameters as well as the parameters from SARC

50 are shown in Table 8. Comparative plots of the two curves for each area are shown in Figure 15. Catch per unit effort (CPUE) of finfish bycatch is shown in Table 9. The distribution and abundance of yellowtail flounder captured by the commercial dredge is shown in Figure 16.

Size selectivity

The catch data was evaluated by the SELECT method with a variety of functional forms (logistic, Richards, log-log) in an attempt to characterize the most appropriate model. Examination of residual patterns model deviance and AIC values indicated that for both cruises the logistic curve provided the best fit to the data. An additional model run was conducted to determine whether the hypotheses of equal fishing intensity (i.e. the two gears fished with equally) were supported. Output for model runs for the logistic function with the split parameter (*p*) both held fixed at the expected value based on gear width and with *p* being estimated is shown in Table 10. Visual examination of residuals and values of model deviance and AIC indicated that in all cases, the model with an estimated split parameter provided the best fit to the data. Fitted curves and deviance residuals for the SNE/LI and NYB cruises are shown in Figures 17-18. Estimated parameters for the final model run excluding tows with less than 50 total scallop caught is shown in Table 11. For the SNE cruise, the estimated L_{50} value was 102.6 mm and the selection range was 22.21 mm. For the NYB cruise, the estimated L_{50} value was 115.6 mm and the selection range was 12.25 mm. It should be noted that the overall catch of scallops in the NYB cruise was fairly low for the survey dredge and that had an impact on the resulting estimates from that cruise. Final selectivity curves for these data sets are shown in Figures 19. A plot comparing the estimated selectivity parameters relative to the degree of survey dredge filling with sand dollars is shown in Figure 20.

The analysis that estimated the relative efficiency of the two gears based upon the expected and observed split parameter values resulted in an relative efficiency value of 2.052 and 5.563 for the SNE and NYB cruises respectively. Assuming the survey dredge operates with 44% efficiency, the expected value for the efficiency of the commercial dredge was 90.2% and 244.9%, respectively. These results are clearly very different from prior experiments and suggest a change in the relative efficiency and perhaps a deviation from the assumption of 44% efficiency of the survey dredge.

Discussion

Fine scale cooperative surveys are an important endeavor. These surveys provide information about subsets of the resource that may not have been subject to intensive sampling by other efforts. This type of survey serves an important function in that the results can be used to redefine the spatial extent of the population and determine whether large numbers of the target organism are present outside of the traditional survey domain.   Finally, this type of survey is important in that it involves the stakeholders of the fishery in the management of the resource.

Our results suggest that for the SNE/LI and NYB areas, significant biomass exists in areas that have traditionally been lightly surveyed. These results will provide some basis for the possible reconfiguration of the survey strata or at least a re-allocation of effort to capture the current distribution of scallops in the surveyed areas. For areas that had been dominated by a large size class, there appears to have been some recruitment in the areas and that the age distribution suggests incoming year classes may support further commercial landings from these areas. While fairly widespread and numerous in the SNE, these size classes, however, were spatially limited in the NYB and their overall extent in that area was not remarkable. Overall, finfish bycatch was generally low and yellowtail flounder bycatch in particular was limited in scale and spatially centered on an area between Martha's Vineyard and Block Island.

The use of commercial scallop vessels in a project of this magnitude presents some interesting challenges. One such challenge is the use of the commercial gear. This gear is not designed to be a survey gear; it is designed to be efficient in a commercial setting. The design of this current experiment however provides insight into the utility of using a commercial gear as a survey tool. One advantage of the use of this gear is that the catch from this dredge represent exploitable biomass and no further correction is needed. A disadvantage lies in the fact that there is very little ability of this gear to detect recruitment events. However, since this survey also utilizes a lined survey dredge, a mechanism to detect recruitment also exists.

The concurrent use of two different dredge configurations provides a means to detect recruitment, test for agreement of results between the two gears and simultaneously conduct size selectivity experiments. In this instance, our experiment provided information regarding a recently mandated change to the commercial gear (CFTDD). While the expectation was that these changes should not affect the size selectivity characteristics of the gear (i.e. L_{50} and SR), as these characteristics are primarily determined by ring and mesh sizes, the possibility exists that the overall efficiency will be altered by different dredge frame design. Our results were indeed similar to those of Yochum and DuPaul (2008) with respect to L_{50} and SR, with the exception of the L_{50} value from the NYB survey. Our estimated *p* values were significantly higher than what was reported in Yochum and DuPaul (2008). These results suggests a couple of possible processes. The first would be that we observed an increase in relative efficiency as a result of the modified dredge frame especially in the smoother substrate of the mid-Atlantic. Secondly, it could be that the survey dredge which acts as a control in the selectivity experiment suffers from a reduction in efficiency as a result of large catches of sand dollars. This is supported by the results in Figure 20 and suggests that the assumption of stable survey dredge efficiency might be erroneous. Results seem to support an intuitive explanation of the effect of the dredge filling with sand dollars. That process appears to do two things to the dredge. First in the case of the survey dredge, the bag becomes so full with sand dollars that simply no more material can fit in the bag and it is regurgitated out the mouth. . While not quite as extreme, a smaller mass of sand dollars serves to raise the bale and sweep chain off the sea floor reducing efficiency. In the case of the commercial dredge, the dredge functions to expectation up to a point, but when large numbers of sand dollars begin to be retained by the dredge, the selective characteristics change (i.e. L_{50} decreases and SR increases) as the rings become clogged and retain smaller scallops than expected. At some point the efficiency of the commercial dredge will also decrease as a result of the same processes that impact the survey dredge. At that point the relative efficiency will decrease as the efficiency of both dredges decrease in kind. The analyses depicted in Figure 20 support this hypothesis and show a decreasing L_{50} as dredge fullness increases. In addition, SR is shown to increase as the dredge fills with sand dollars. With respect to the split parameter, *p*, it appears that as the survey dredge fills with sand dollars there is a general decrease in relative efficiency. As the density of sand dollars is so great that both dredges begin to fill, then there is a decrease in the efficiency of both dredges and the relative difference is reduces as demonstrated by the decrease in estimated *p* at high dredge fullness values.

One caveat, however, is that for the NYB trip in particular and both trips in general, overall catch was low which precluded a selectivity analysis that estimates selectivity parameters on a tow by tow basis. With this analysis, covariates can be examined and their degree of influence on parameter estimates quantified. The data was simply too limited to complete that type of analysis and a simpler regression type approach was used. Given the major role that dredge efficiency plays in the estimates of biomass from dredge surveys, it is clear that this topic is of critical importance its refinement be a high priority.

Biomass estimates are sensitive to other assumptions made about the biological characteristics of the resource; specifically, the use of appropriate shell height-meat weight parameters. There is however, a large variation in this relationship as a result of many factors. Seasonal and inter-annual variation can result in some of the largest differences in shell height-meat weight values. Traditionally, when the sea scallop undergoes its annual spawning cycle, metabolic energy is directed toward the production of gametes and the somatic tissue of the scallop is still recovering and is at some of their lowest levels relative to shell size (Serchuk and Smolowitz, 1989). While accurately representative for the month of the survey, biomass has the potential to be different relative to other times of the year. For comparative purposes, our results were also shown using the parameters from SARC 50 (NEFSC, 2010). These parameters reflect larger geographic regions (mid-Atlantic) and are collected during the summer months. This allowed a comparison of results that may be reflective of some of the variations in biomass due to the fluctuations in the relationship between shell height and adductor muscle weight. Parameters generated from data collected during the course of the study were appropriate for the area and time sampled and in general showed larger meats relative to shell than the SARC 50 relationships. The high yield from these areas has been observed and exploited by industry and may result from a general shallower depth profile, or some environmental factor that promotes above average animal condition. The SARC 50 relationship has traditionally not included samples from this area, and as a result, may not capture the potential unique characteristics of those areas. It must be noted that our results are only a snapshot in both time and space and do not capture long term averages as well as the SARC 50 relationships. Area and time specific shell height-meat weight parameters are another topic that merits consideration.

The survey of the SNE/LI and NYB areas during the summer of 2011 provided a high-resolution view of the resource in these areas. The SNE/LI and NYB areas are unique in that they will play a critical role in the management strategy of the sea scallop resource over the next few years. With the closed areas of the mid-Atlantic (Elephant Trunk and DelMarVa) nearing the end of their rotational cycles, the SNE/LI and NYB areas will become increasingly more important. While the data and subsequent analyses provide an additional source of information on which to base management decisions, it also highlights the need for further refinement of some of the components of industry based surveys. The use of industry based cooperative surveys provides an excellent mechanism to obtain the vital information to effectively regulate the sea scallop fishery.

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Table 1 Summary statistics for the survey cruise.

Area	Cruise dates	Number of stations included in biomass estimate (survey dredge)	Number of stations included in biomass estimate (comm. dredge)
Southern New England/Long Island	June 25-30, 2011	103	103
New York Bight	August 31-Sept. 6, 2011	101	101

Table 2 Mean total and mean exploitable scallop densities observed during the 2011 cooperative sea scallop surveys of SNE/LI and NYB.

	Efficiency	**Average Total Density (scallops/m^2)**	**SE**	**Average Density of Exploitable Scallops (scallops/m^2)**	**SE**
SNE					
Commercial	65%			0.041	0.004
Survey	44%	0.061	0.006	0.036	0.004
NYB					
Commercial	65%			0.018	0.002
Survey	44%	0.015	0.003	0.008	0.001

Table 3 Estimated number of scallops in the area surveyed. The estimate is based upon the estimated density of scallops at commercial dredge efficiency of 65% and survey dredge efficiency of 44%. The spatial extent of the survey areas were estimated at 11,203 km^2 (SNE/LI) and 7,634 km^2 (NYB).

	Efficiency	Estimated Total	Estimated Total Exploitable
SNE			
Commercial	65%		455,277,587
Survey	44%	680,541,651	400,618,210
NYB			
Commercial	65%		134,887,158
Survey	44%	112,544,513	63,676,272

<u>Table 4</u> Estimated average scallop meat weights for the area surveyed. Estimated weights are for the total size distribution of animals as represented by the catch from the NMFS survey dredge as well as the mean weight of exploitable scallops in the area as represented by the catches from both the survey and commercial dredge. Length:weight relationships from both SARC 50 as well as that observed from the cruise are shown.

	SH:MW	Mean Meat Weight (g) Total scallops	Mean Meat Weight (g) Exploitable scallops
SNE			
Commercial	SARC 50 MAB		31.98
Survey	SARC 50 MAB	24.70	31.05
Commercial	VIMS DEPTH WEIGHTED		38.32
Survey	VIMS DEPTH WEIGHTED	30.05	37.26
NYB			
Commercial	SARC 50 MAB		45.15
Survey	SARC 50 MAB	26.19	36.07
Commercial	VIMS DEPTH WEIGHTED		49.49
Survey	VIMS DEPTH WEIGHTED	31.13	41.38

Table 5 Mean catch of sea scallops observed during the 2011 VIMS-Industry cooperative surveys. Mean catch is depicted as a function of various shell height meat weight relationships, either an area specific relationship derived from samples taken during the survey, or a relationship from SARC 50.

	Samples	SH:MW	Mean Total (grams/tow)	Standard Error
SNE				
Survey	103	SARC 50 MAB	2,857.30	270.06
Survey	103	VIMS DEPTH WEIGHTED	3,476.56	333.53
NYB				
Survey	101	SARC 50 MAB	764.99	120.01
Survey	101	VIMS DEPTH WEIGHTED	909.23	148.69

	Samples	SH:MW	Mean Exploitable (grams/tow)	Standard Error
SNE				
Commercial	103	SARC 50 MAB	6,864.01	548.81
Survey	103	SARC 50 MAB	2,112.52	192.74
Commercial	103	VIMS DEPTH WEIGHTED	8,222.86	663.62
Survey	103	VIMS DEPTH WEIGHTED	2,534.83	233.10
NYB				
Commercial	101	SARC 50 MAB	4,420.95	546.15
Survey	101	SARC 50 MAB	597.60	87.73
Commercial	101	VIMS DEPTH WEIGHTED	4,845.92	605.90
Survey	101	VIMS DEPTH WEIGHTED	685.55	103.61

Table 6 Estimated total biomass of sea scallops observed during the 2011 VIMS-Industry cooperative surveys. Biomass is presented as a function of different shell height meat weight relationships, either an area specific relationship derived from samples taken during the actual survey or a relationship from SARC 50.

	SH:MW	Efficiency	Total Biomass (mt)	95% CI	Lower Bound 95% CI	Upper Bound 95%CI
SNE						
Survey	SARC 50 MAB	44%	16,676.32	2,049.23	14,627.08	18,725.55
Survey	VIMS DEPTH WEIGHTED	44%	20,290.58	2,530.82	17,759.76	22,821.40
NYB						
Survey	SARC50 MAB	44%	2,927.79	597.15	2,330.64	3,524.94
Survey	VIMS DEPTH WEIGHTED	44%	3,479.81	739.86	2,739.95	4,219.68

Table 7 Estimated exploitable biomass of sea scallops observed during the 2011 VIMS-Industry cooperative surveys. Biomass is presented as a function of different shell height meat weight relationships, either an area specific relationship derived from samples taken during the actual survey or a relationship from SARC 50.

	SH:MW	**Efficiency**	**Exploitable Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
SNE						
Commercial	SARC 50 MAB	65%	14,463.07	1,827.35	12,635.72	16,290.42
Survey	SARC 50 MAB	44%	12,329.52	1,462.47	10,867.04	13,791.99
Commercial	VIMS DEPTH WEIGHTED	65%	17,326.29	2,209.62	15,116.67	19,535.91
Survey	VIMS DEPTH WEIGHTED	44%	14,794.29	1,768.78	13,025.51	16,563.07
NYB						
Commercial	SARC 50 MAB	65%	6,108.53	1,192.47	4,916.06	7,300.99
Survey	SARC 50 MAB	44%	2,287.13	436.52	1,850.61	2,723.65
Commercial	VIMS DEPTH WEIGHTED	65%	6,695.72	1,322.92	5,372.80	8,018.64
Survey	VIMS DEPTH WEIGHTED	44%	2,623.77	515.57	2,108.20	3,139.33

Table 8 Summary of area specific shell height-meat weight parameters used in the analyses. Parameters were obtained from two sources: (1) samples collected during the course of the surveys, and (2) SARC 50 (NEFSC, 2010).

	Date	α	β	γ	δ
Survey Data					
SNE/LI	June, 2011	-8.8079	2.7546	-0.1859	
NYB	Sept., 2011	-7.8163	2.5077	-0.1343	
SARC 50					
Mid-Atlantic general		-16.88	4.64	1.57	-0.43

*The length weight relationship for sea scallops from data collected on the cruise is modeled as:

$$W=\exp(\alpha+ \beta^*\ln(L) + \gamma^*\ln(D))$$

For SARC 50 (mid-Atlantic) an interaction term is included in the model as follows:

$$W=\exp(\alpha+ \beta^*\ln(L) + \gamma^*\ln(D) + \delta^*\ln(L)^*\ln(D))$$

Where *W* is meat weight in grams, *L* is scallop shell height in millimeters (measured from the umbo to the ventral margin) and *D* is depth in meters.

<u>Table 9</u> Catch per unit effort (a unit of effort is represented by one standard survey tow of 15 minute duration at 3.8-4.0 kts.) of finfish bycatch encountered during the survey of the SN/LI and NYB areas during 2011. In total, finfish bycatch was measured and recorded for 103 and 101 survey tows on the SNE/LI and NYB trips, respectively.

Southern New England

Common Name	Scientific Name	Commercial Dredge	Survey Dredge
Unclassified Skates	Raja spp.	42.14	15.30
Barndoor Skate	Raja laevis	0.34	0.12
American Plaice	Hippoglossoides platessoides	0.00	0.04
Summer Flounder	Paralichtys dentatus	0.01	0.03
Fourspot Flounder	Paralichtys oblongotus	1.10	3.57
Yellowtail Flounder	Limanda ferruginea	1.43	1.55
Blackback Flounder	Psuedopleuronectes americana	0.28	0.49
Witch Flounder	Glyptocephalus cynoglossus	0.00	0.02
Windowpane Flounder	Scophthalmus aquasus	0.36	0.23
Monkfish	Lophius americanus	1.66	0.70

New York Bight

Common Name	Scientific Name	Commercial Dredge	Survey Dredge
Unclassified Skates	Raja spp.	26.66	8.92
Summer Flounder	Paralichtys dentatus	0.20	0.10
Fourspot Flounder	Paralichtys oblongotus	0.19	1.41
Yellowtail Flounder	Limanda ferruginea	0.00	0.02
Blackback Flounder	Psuedopleuronectes americana	0.02	0.02
Windowpane Flounder	Scophthalmus aquasus	3.86	1.50
Monkfish	Lophius americanus	0.23	0.10

Table 10 Selection curve parameter estimates and hypotheses test. Selectivity data for each cruise was evaluated by a logistic curve with and without the split parameter (*p*) estimated. Improvements with respect to model fit were assessed by an examination of model deviance and AIC values.

Southern New England/Long Island

	Fixed *p*	**Estimated *p***
a	-10.8824	-10.0661
b	0.1422	0.09801
p	0.5	.7822
L_{25}	68.80	91.49
L_{50}	76.52	102.69
L_{75}	84.25	113.90
Selection Range (SR)	15.45	22.41
Model Deviance	63.84	2.67
Degrees of Freedom	28	27
AIC	126.2	64.9

New York Bight

	Fixed *p*	**Estimated *p***
a	-27.854	-20.8526
b	0.2622	0.1804
p	0.5	0.9065
L_{25}	102.02	109.51
L_{50}	106.21	115.6
L_{75}	110.40	121.7
Selection Range (SR)	8.37	12.17
Model Deviance	73.9	1.15
Degrees of Freedom	30	29
AIC	107.1	36.3

Table 11 Estimated logistic SELECT model fit for tows with total catch of greater than 50 scallops. Estimated parameters *a*, *b* and *p* as well as the length at 50% retention (L_{50}) and Selection Range (SR) are shown. The number of valid tows, as well as the replication estimate of between-haul variation (REP) is shown. These data sets were determined to not be overdispersed and did not require an adjustment to the standard errors.

Southern New England/Long Island

	SNE/LI	
Length Classes		
a	-10.1521	2.98
b	0.0989	0.03
p	0.7822	0.05
L_{50}	102.6	3.01
Selection Range	22.21	2.97
REP	N/A	
# of tows in analysis	100	

New York Bight

	NYB	
Length Classes	45-155	
a	-20.743	7.79
b	0.1793	0.07
p	0.9069	0.04
L_{50}	115.6	9.41
Selection Range	12.25	5.85
REP	N/A	
# of tows in analysis	80	

Figure 1 Locations of sampling stations for the Southern New England/Long Island survey conducted by the F/V *Celtic* during June, 2011.

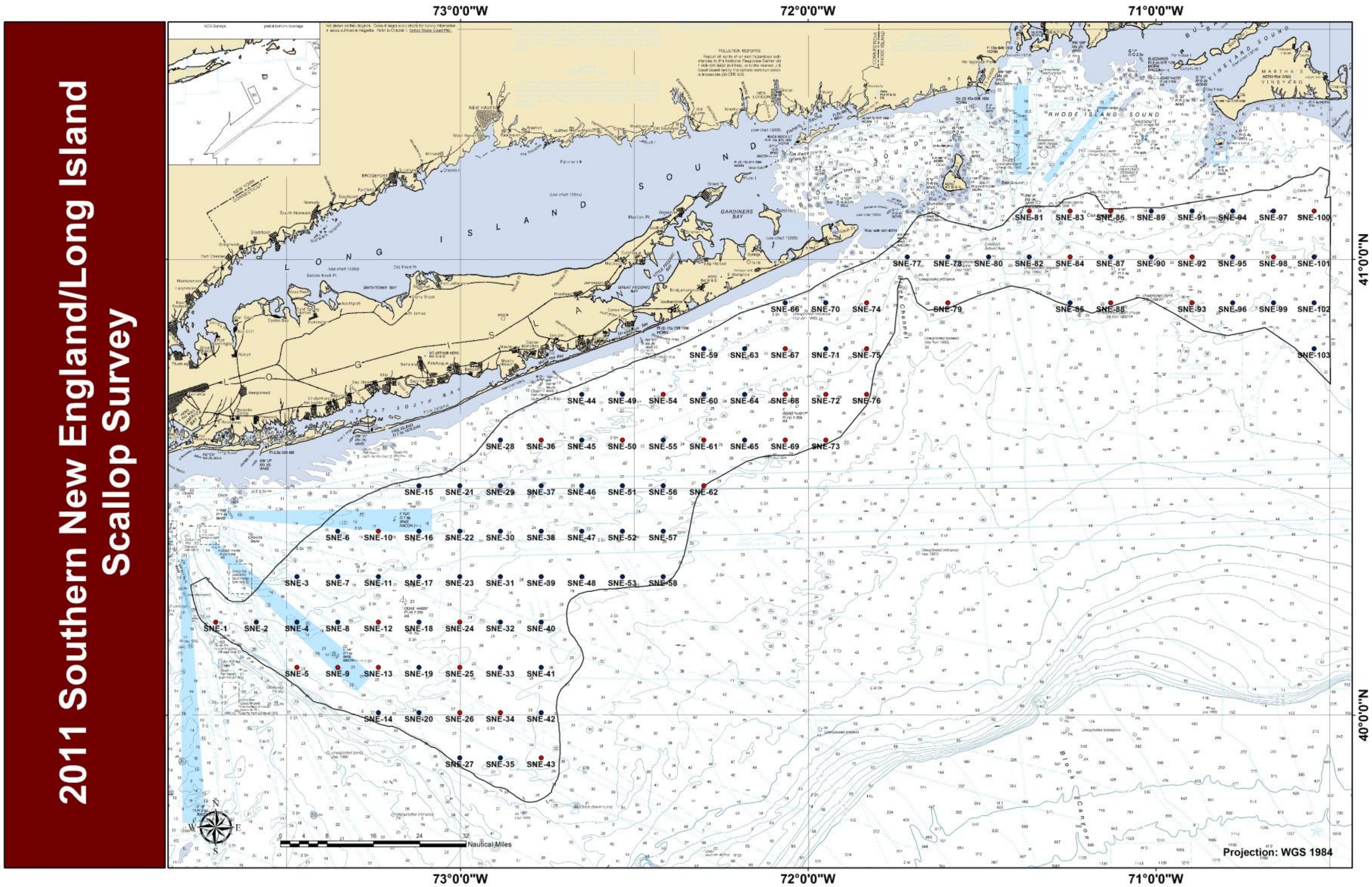


Figure 2 Locations of sampling stations for the New York Bight survey conducted by the F/V *Kathy Ann* during August-September, 2011.

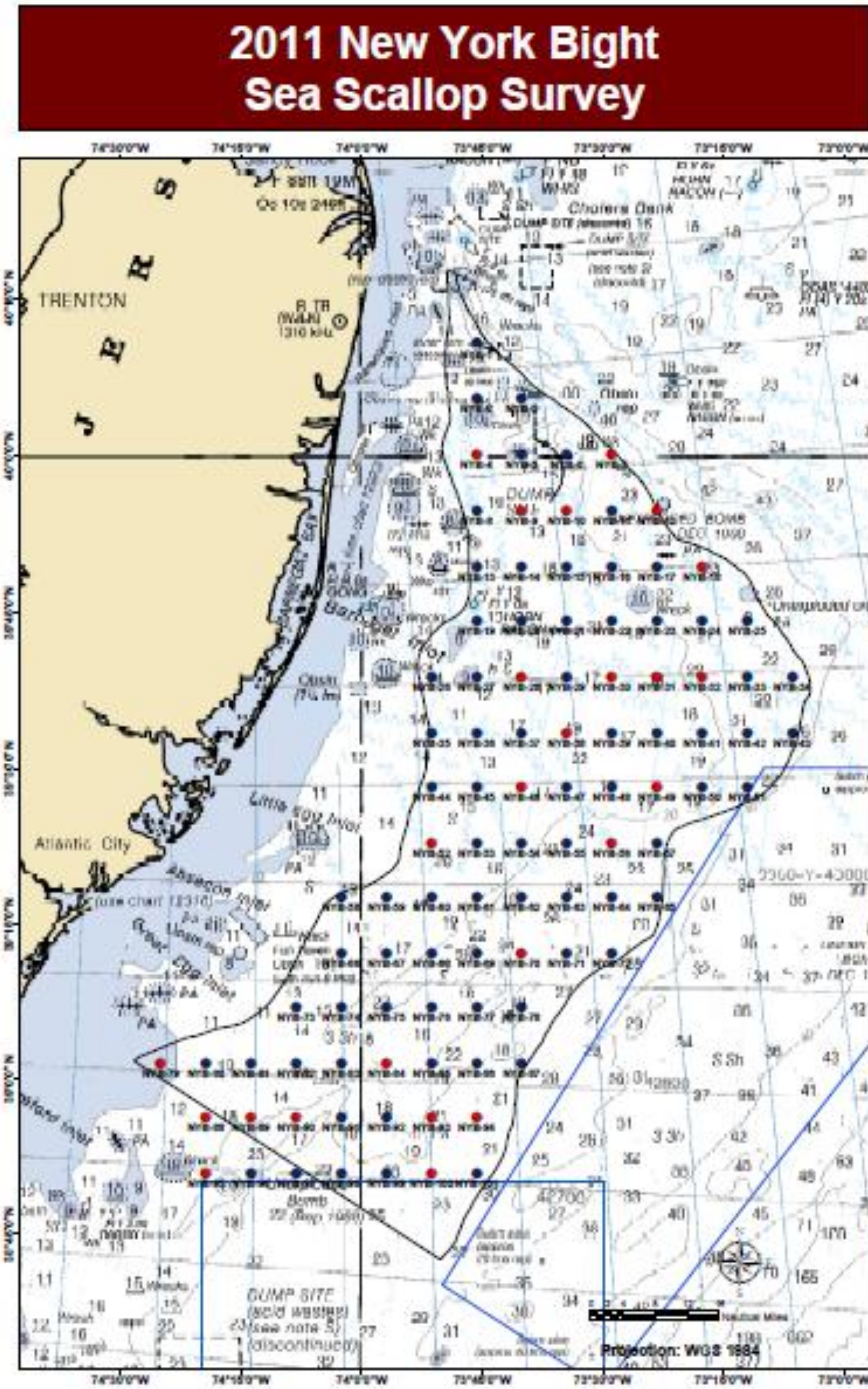
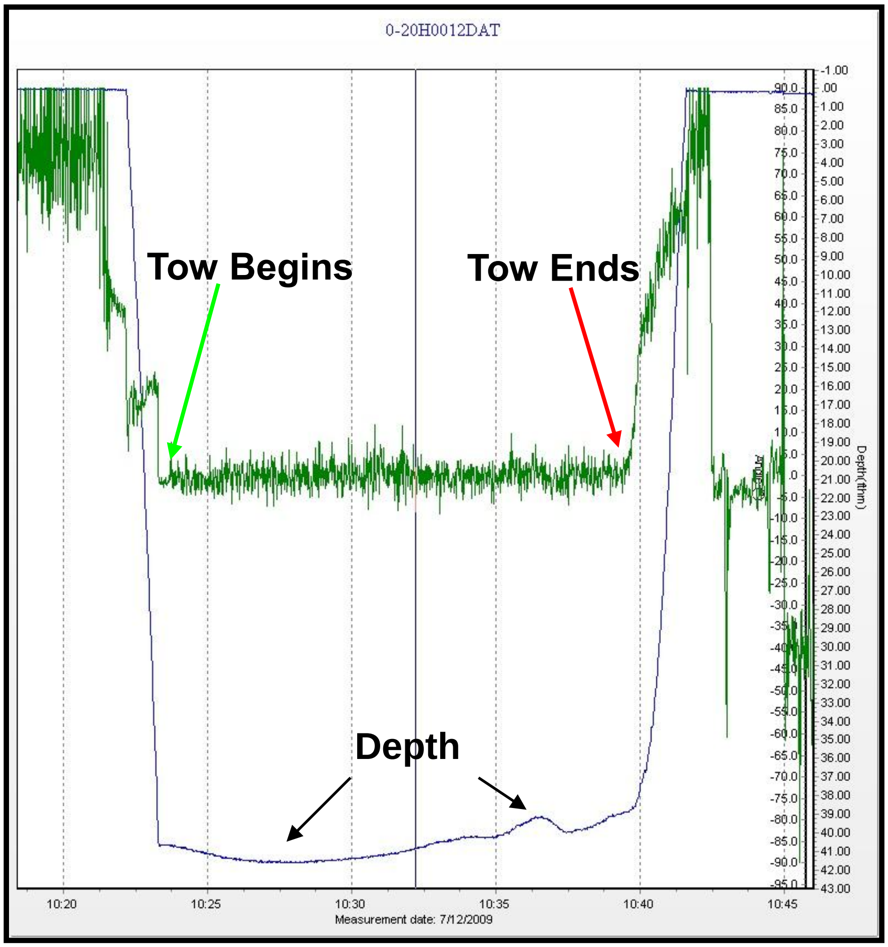
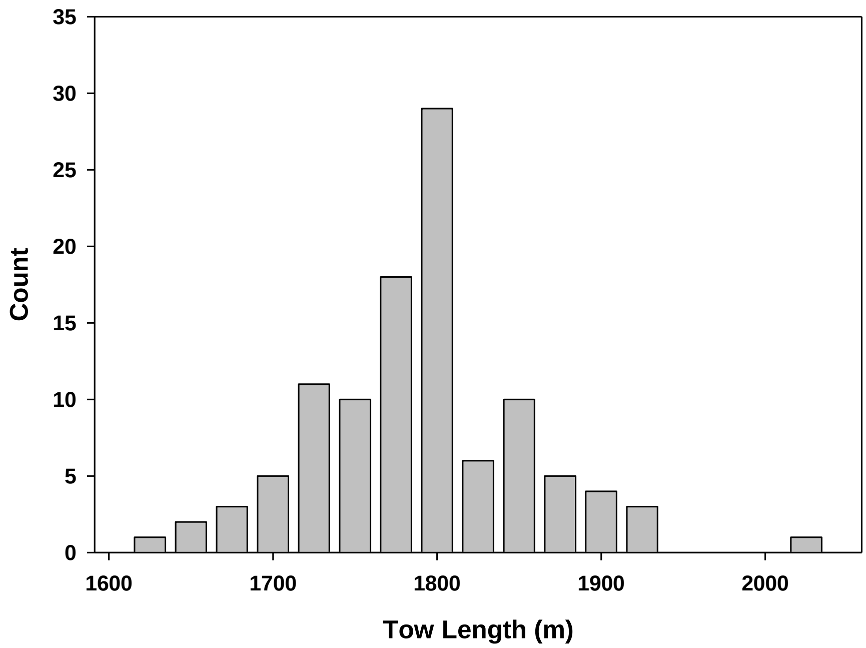


Figure 3 An example of the output Star-Oddi™ DST sensor. Arrows indicate the interpretation of the start and end of the dredge tow



<u>Figure 4</u> Histogram of calculated tow lengths from the 2011 surveys of SNE/LI and NYB. Mean tow length for the SNE/LI survey was 1788.6 m with a standard deviation of 65.0 m. Mean tow length for the NYB survey was 1859.1 m with a standard deviation of 47.0 m.

Southern New England/Long Island



New York Bight

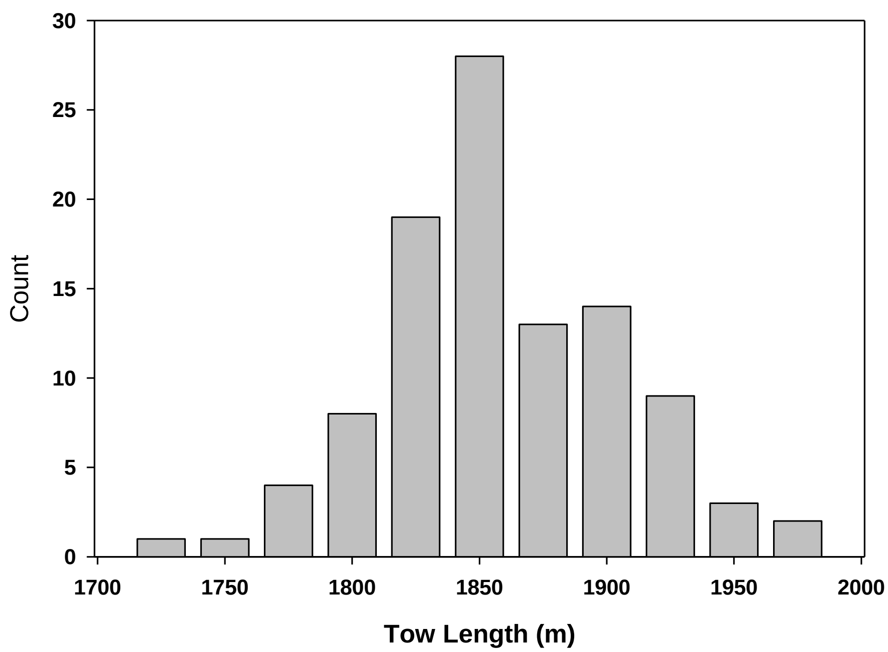


Figure 5 Shell height frequencies for the two dredge configurations used to survey the Southern New England/Long Island area during June of 2011. The frequencies represent the expanded but unadjusted catches of the two gears for all sampled tows.

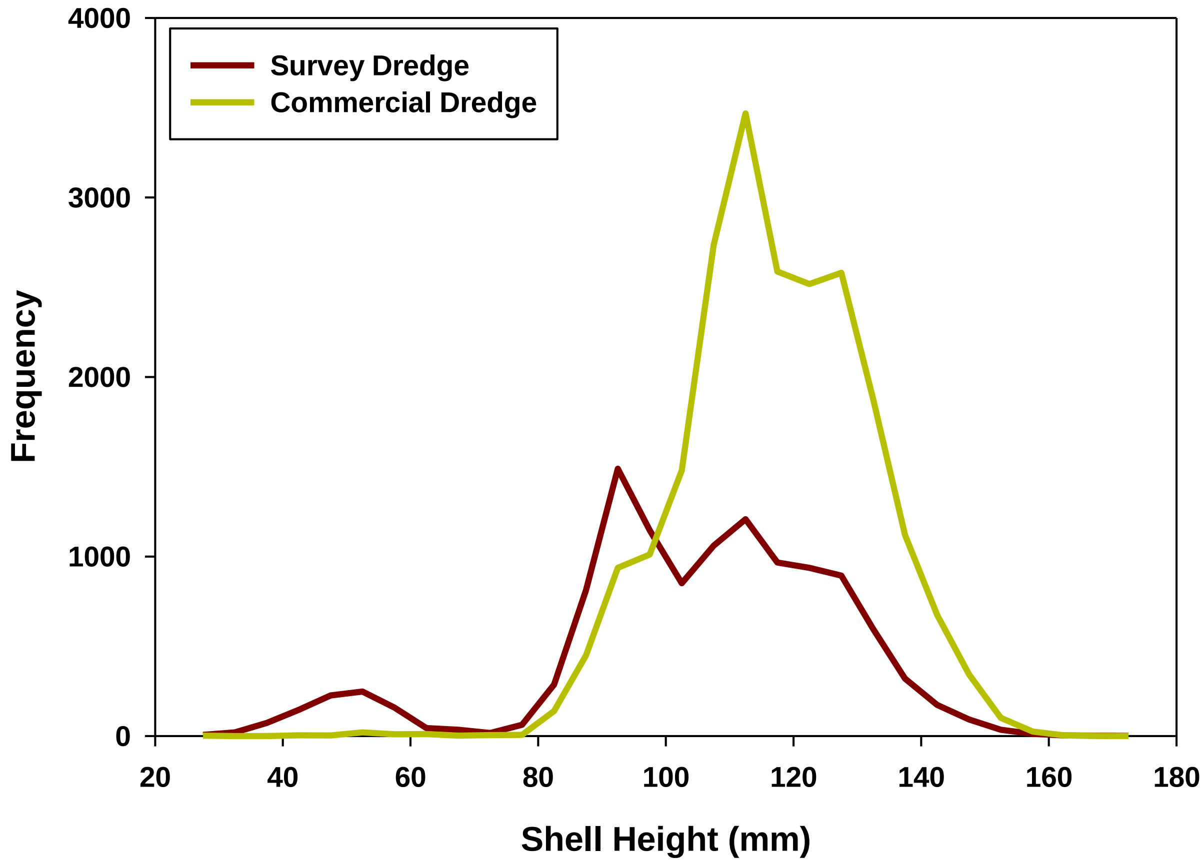


Figure 6 Shell height frequencies for the two dredge configurations used to survey the New York Bight area during early September, 2011. The frequencies represent the expanded but unadjusted catches of the two gears for all sampled tows.

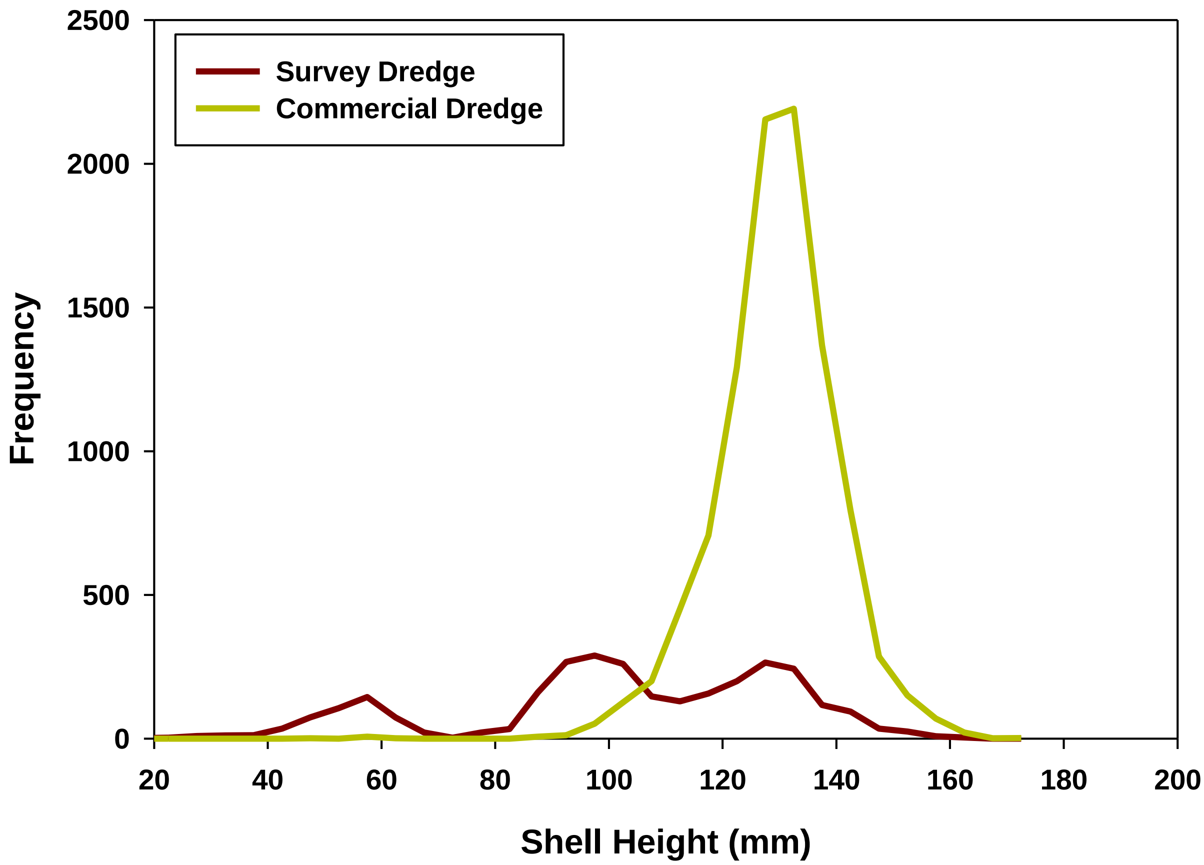


Figure 7 Spatial distribution of sea scallop catches on survey cruise of Southern New England/Long Island during June, 2011 by the NMFS survey dredge. This figure represents the catch of pre-recruit sea scallops (<70mm).

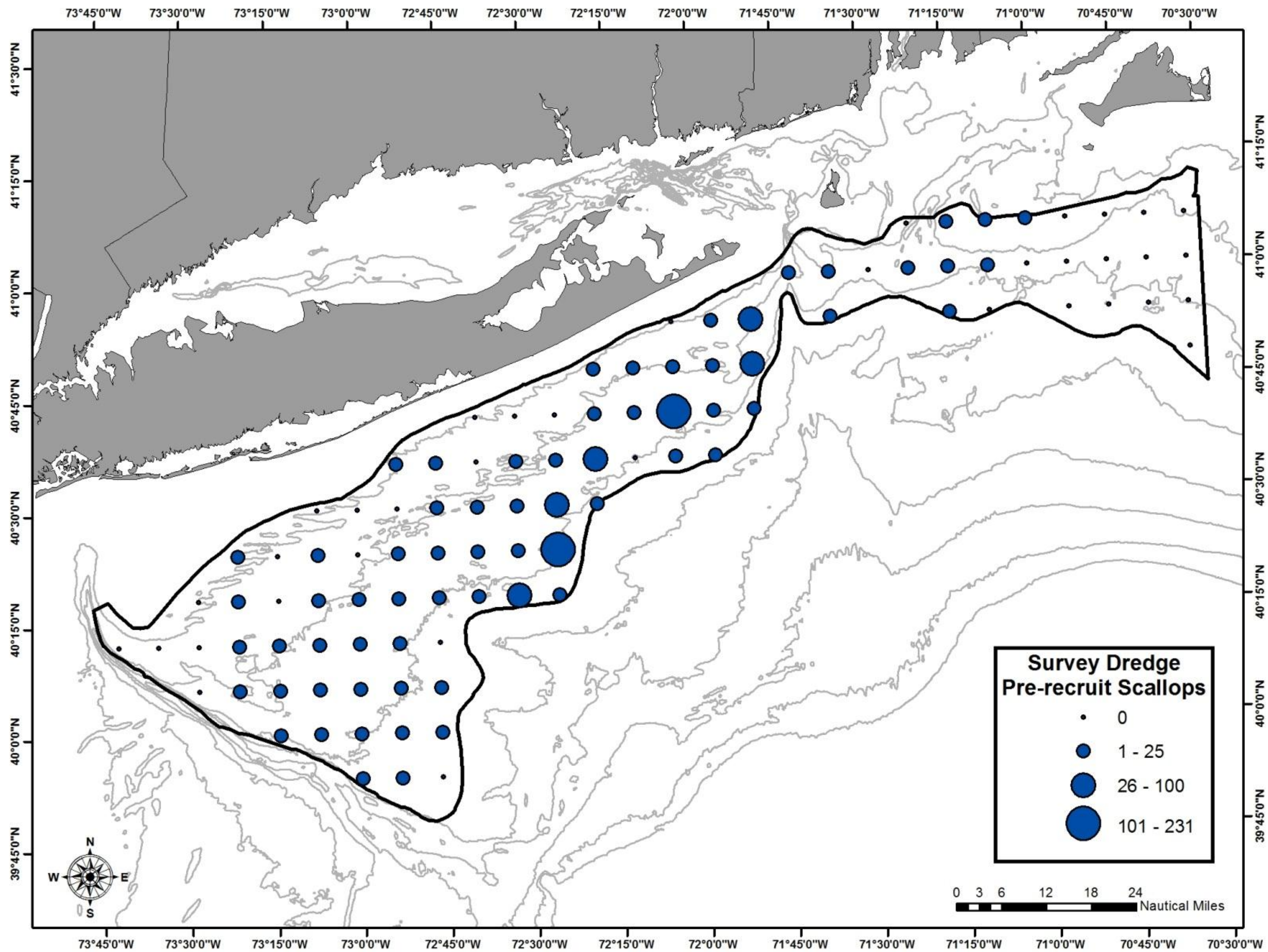


Figure 8 Spatial distribution of sea scallop catches on survey cruise of Southern New England/Long Island during June, 2011 by the NMFS survey dredge. This figure represents the catch of recruit sea scallops (>70 mm).

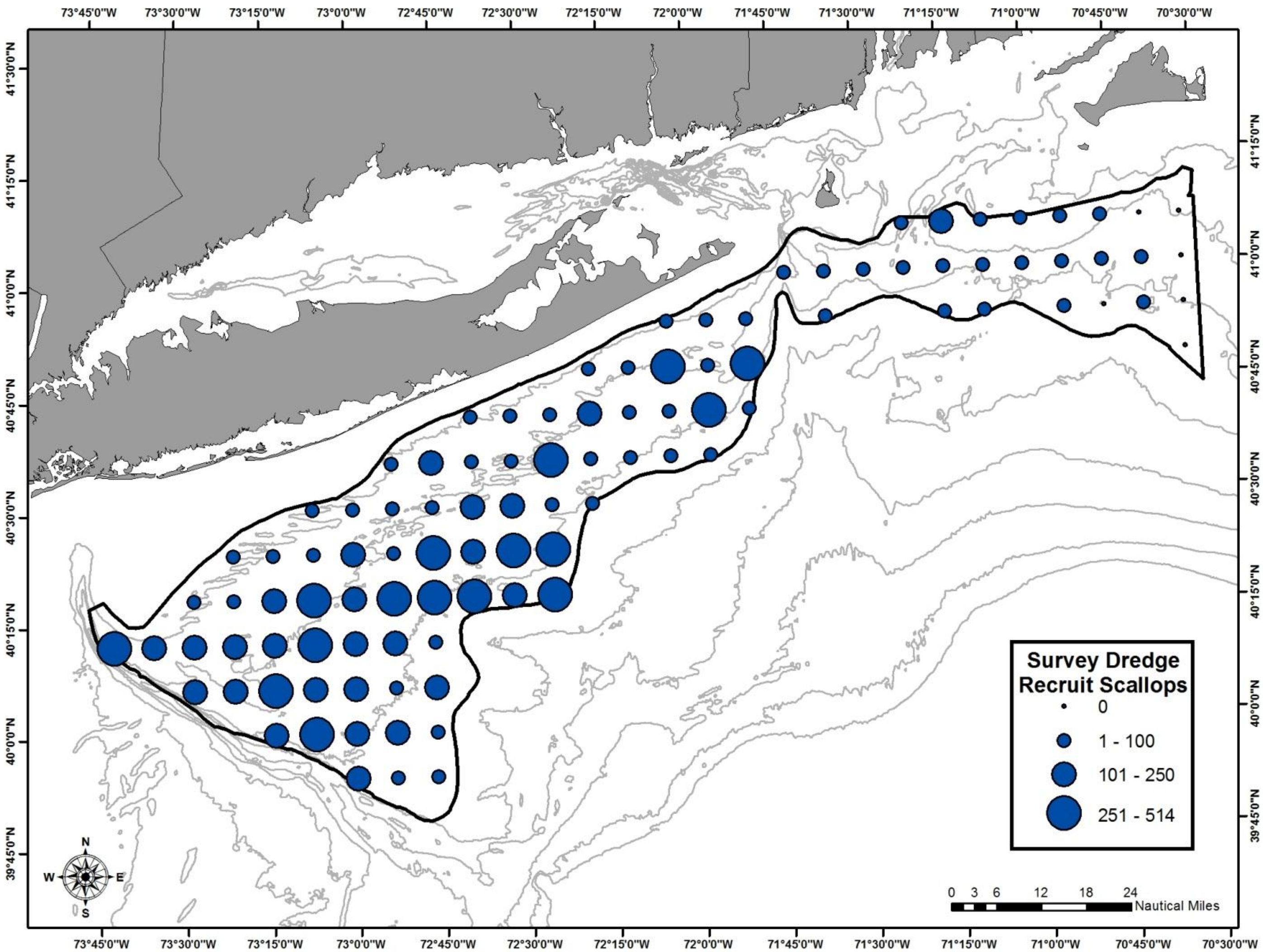


Figure 9 Spatial distribution of sea scallop catches on survey cruise of Southern New England/Long Island during June, 2011 by the CFTDD. This figure represents the catch of pre-recruit sea scallops (<70mm).

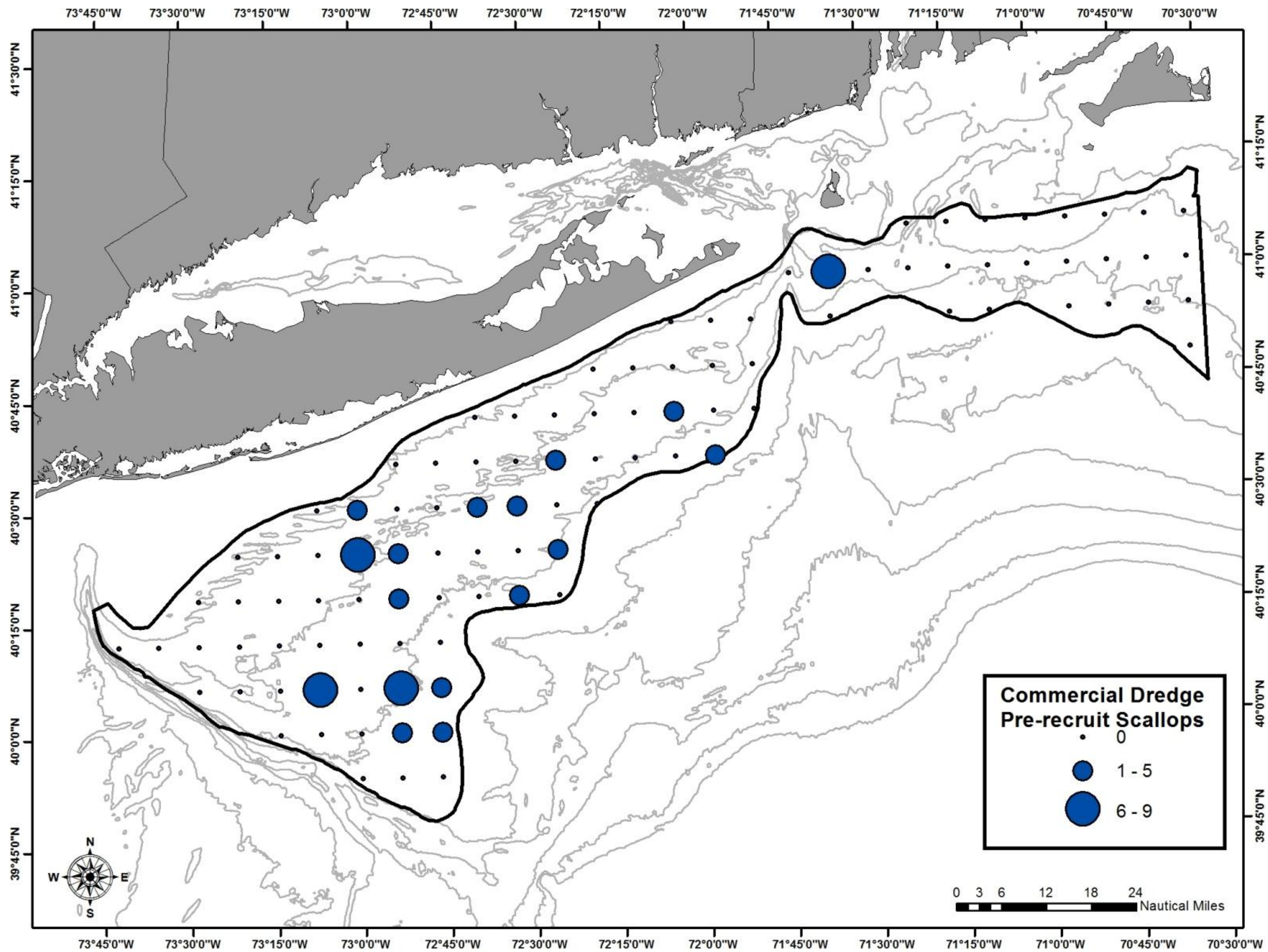


Figure 10 Spatial distribution of sea scallop catches on survey cruise of Southern New England/Long Island during June, 2011 by the CFTDD. This figure represents the catch of recruit sea scallops (>70 mm).

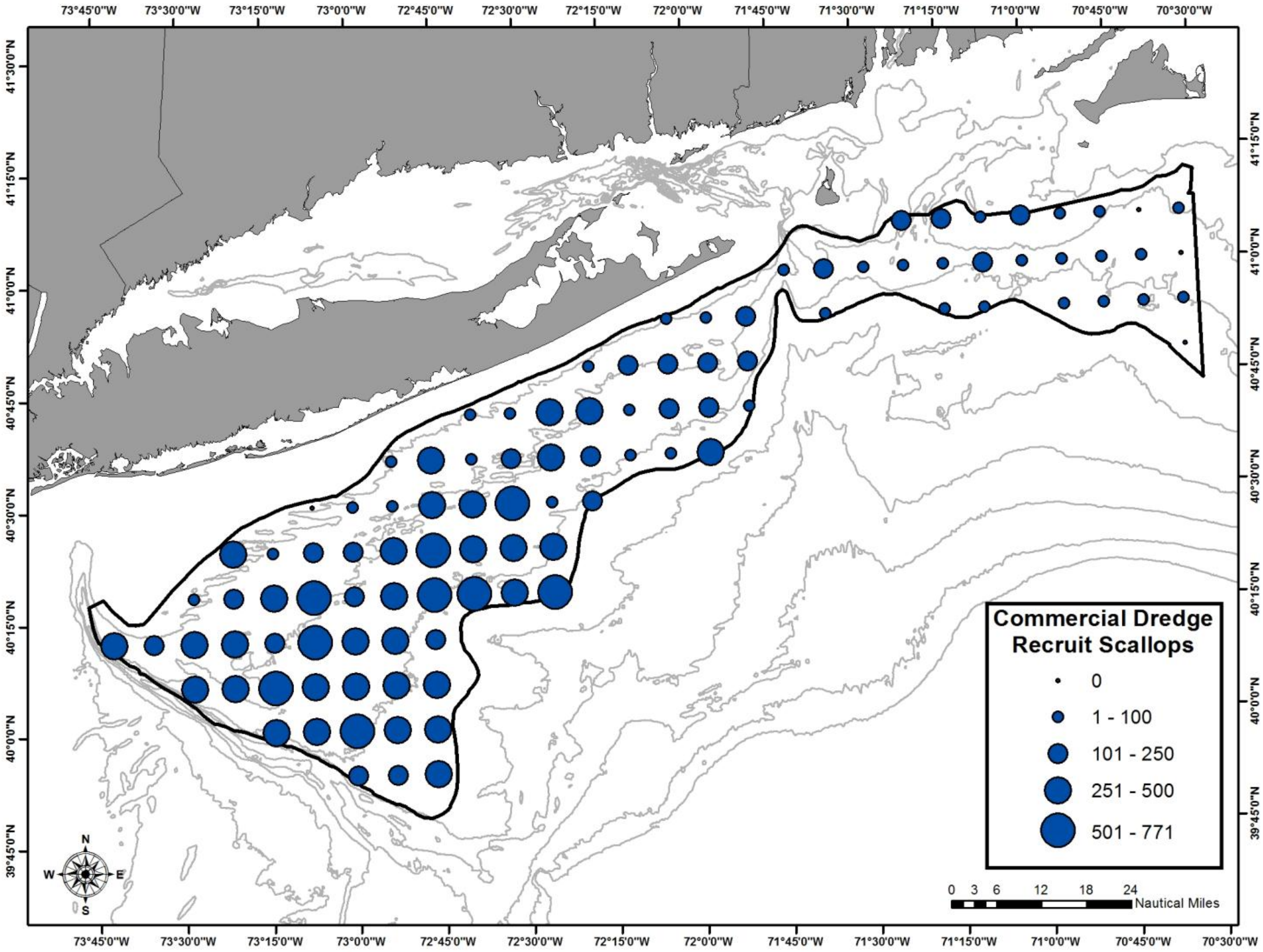


Figure 11 Spatial distribution of sea scallop catches on survey cruise of New York Bight during September, 2011 by the NMFS survey dredge. This figure represents the catch of pre-recruit sea scallops (<70mm).

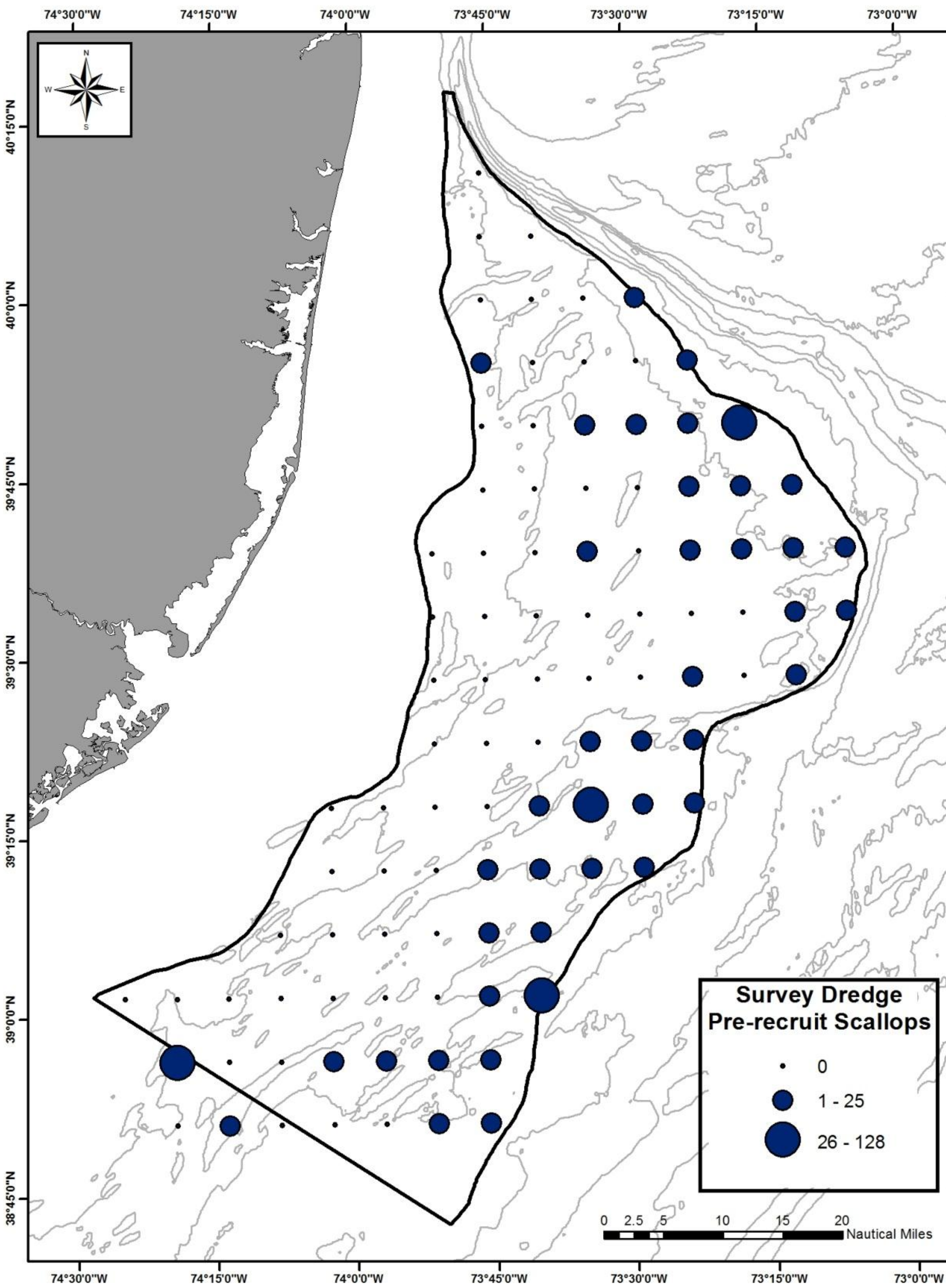


Figure 12 Spatial distribution of sea scallop catches on survey cruise of New York Bight during September, 2011 by the NMFS survey dredge. This figure represents the catch of recruit sea scallops (>70 mm).

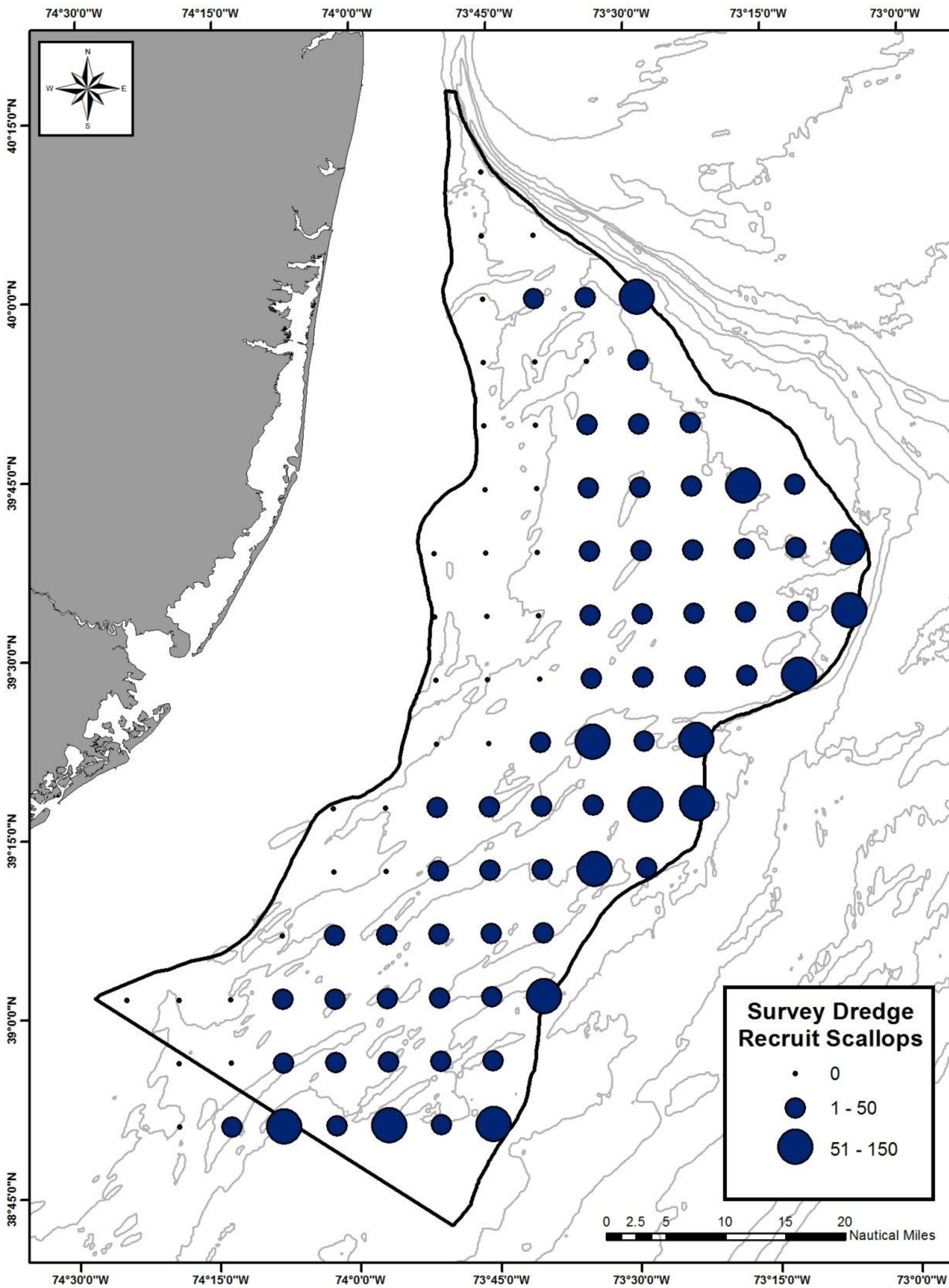


Figure 13 Spatial distribution of sea scallop catches on survey cruise of New York Bight during September, 2011 by the NMFS survey dredge. This figure represents the catch of pre-recruit sea scallops (<70mm).

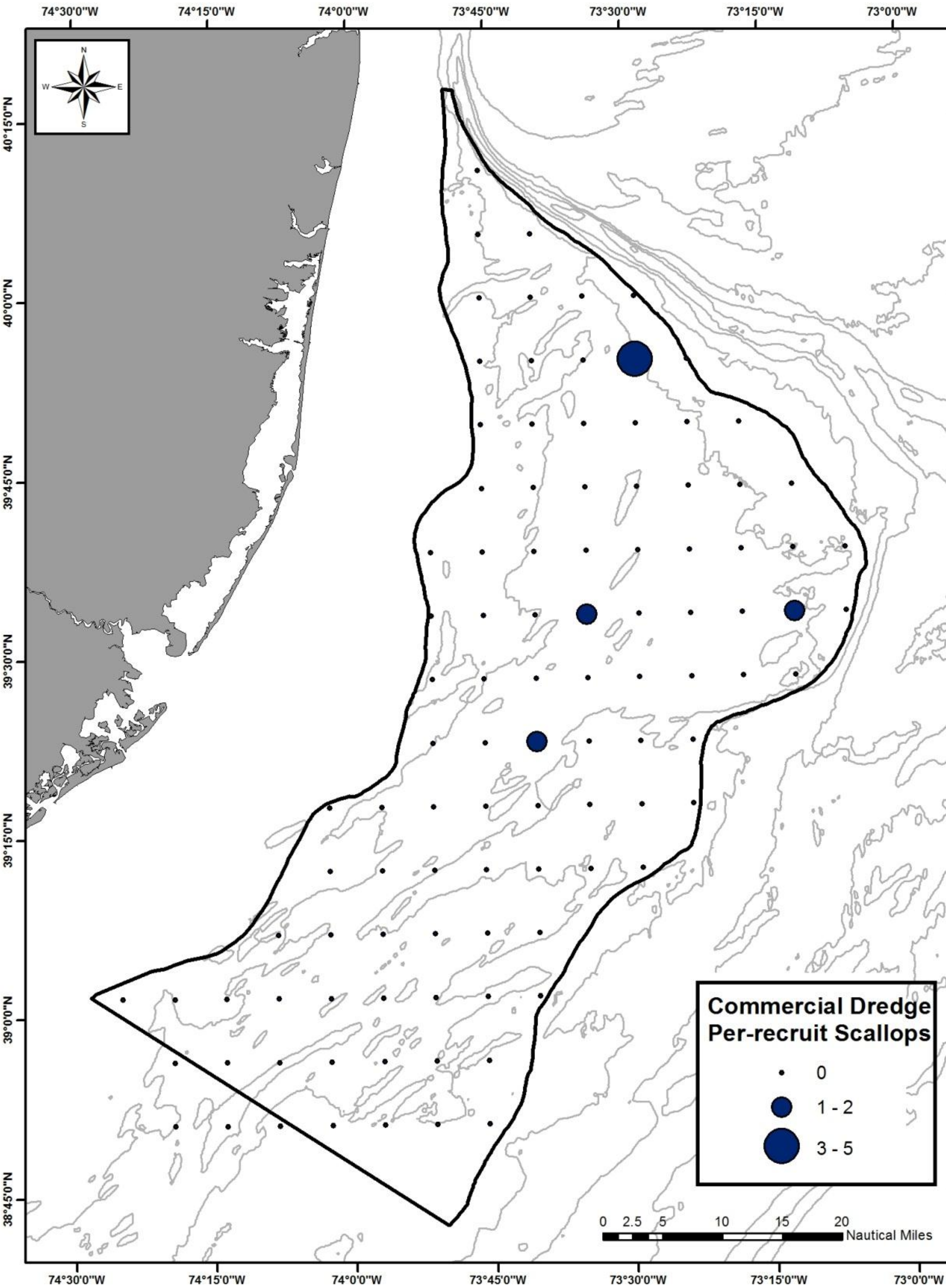


Figure 14 Spatial distribution of sea scallop catches on survey cruise of New York Bight during September, 2011 by the NMFS survey dredge This figure represents the catch of recruit sea scallops (>70 mm).

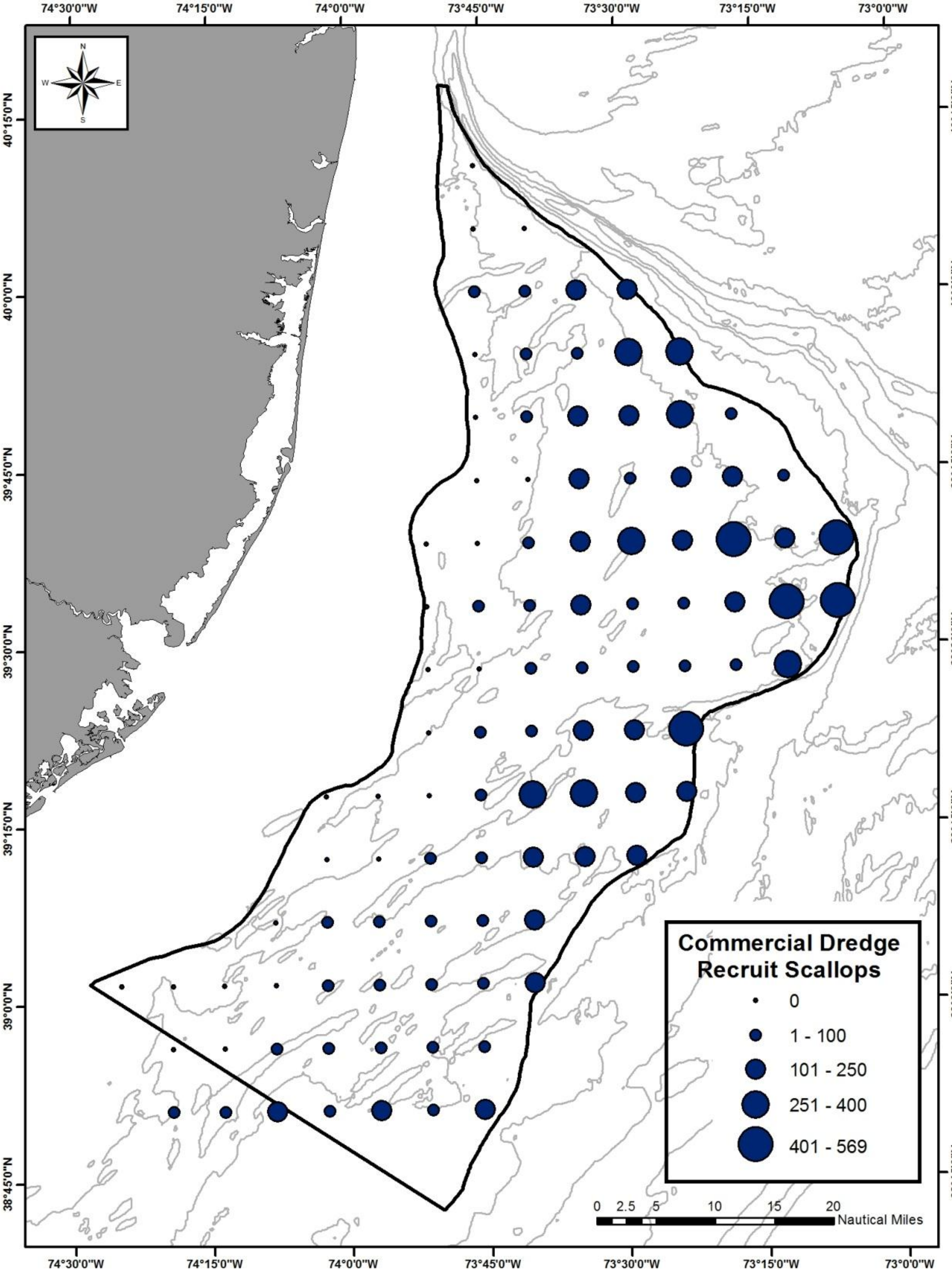
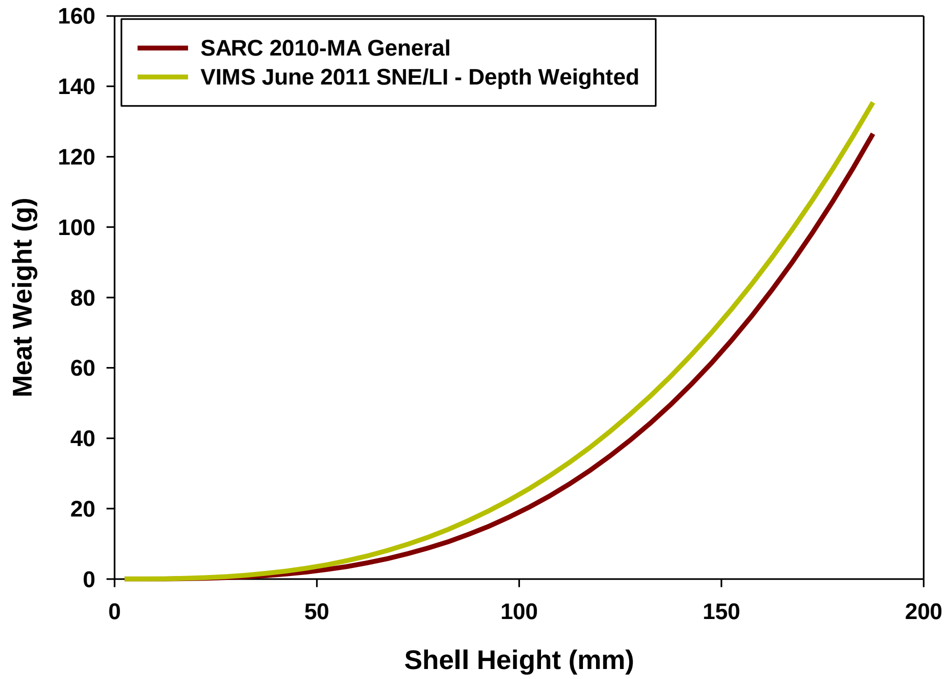


Figure 15 Shell height:meat weight relationships used in the study. The SARC-50 curve is an area specific curve for the entire mid-Atlantic area. The VIMS-2011 curves are based on samples taken during the survey and is specific for the eacharea during the time of the cuise.



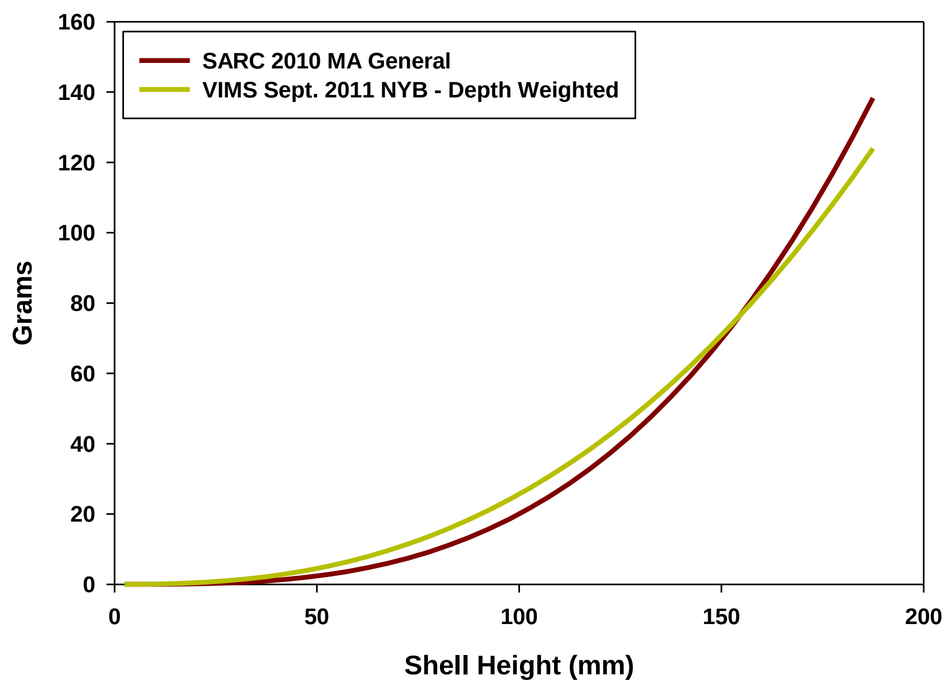


Figure 16 Spatial distribution of yellowtail flounder bycatch survey cruise of Southern New England/Long Island during June, 2011 by the CFTDD. This figure represents the total catch of yellowtail flounder at each tow.

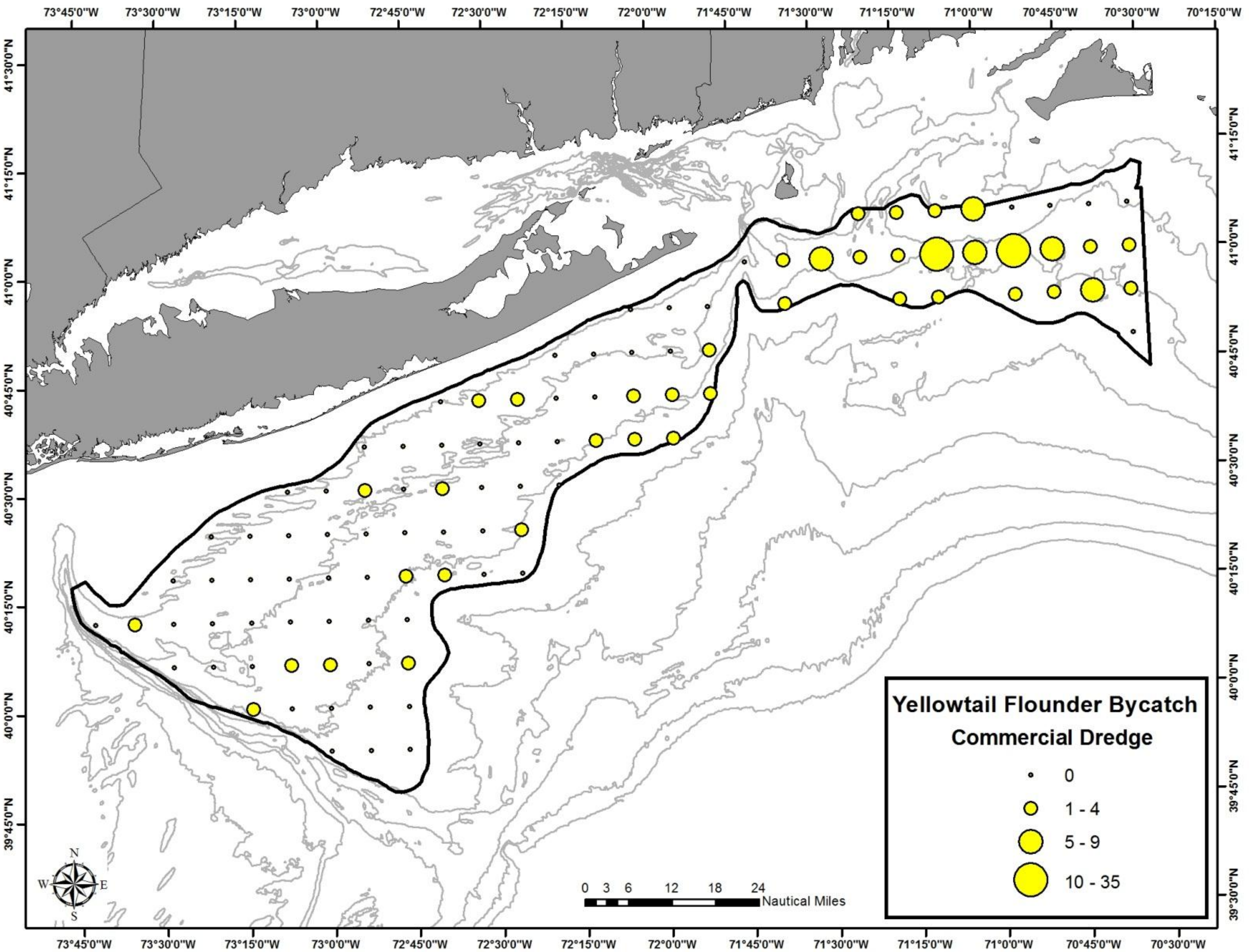
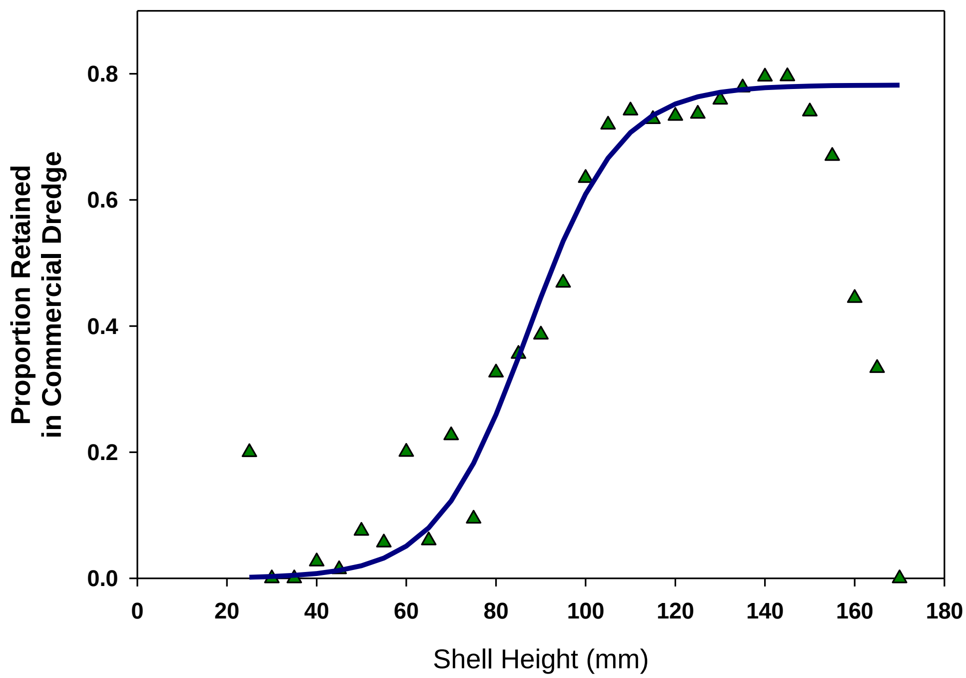
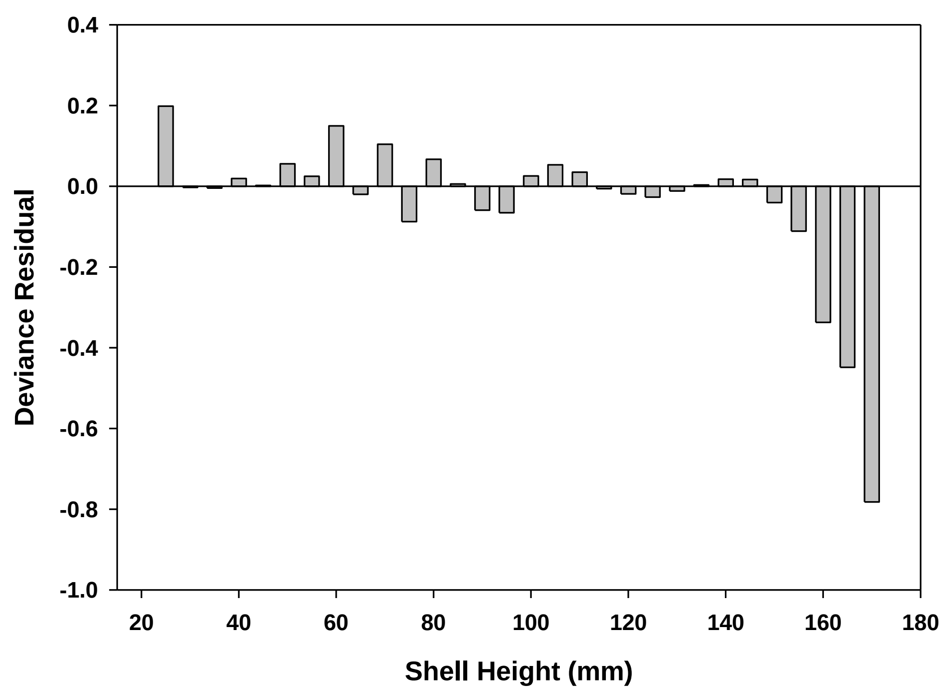
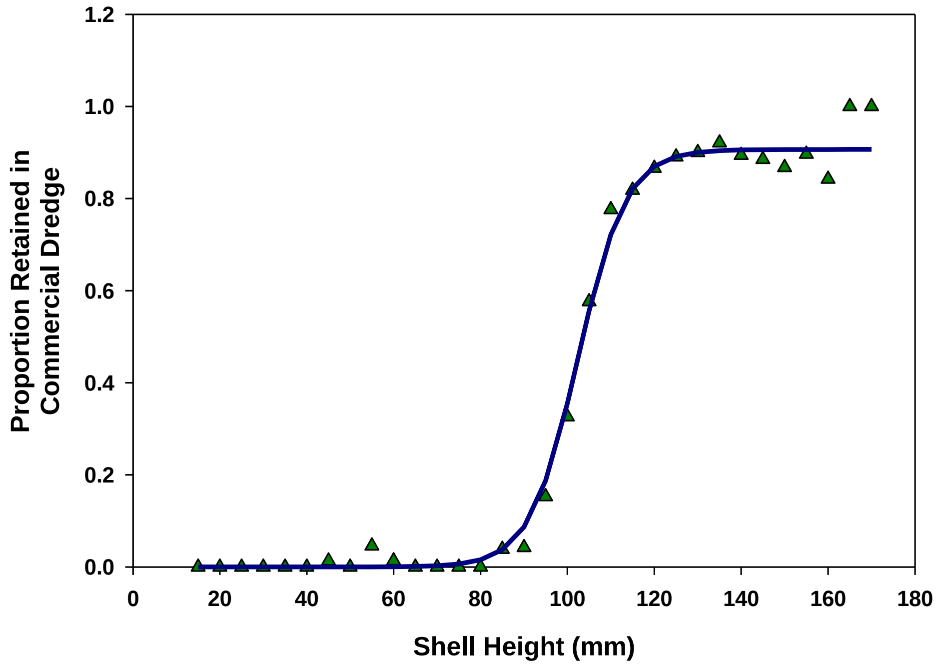


Figure 17 Top Panel: Logistic SELECT curves fit to the proportion of the total catch in the commercial dredge relative to the total catch (survey and commercial) for 2011 cruise to the SNE/LI. Bottom Panel: Deviance residuals for the model fit.





<u>Figure 18</u> Top Panel: Logistic SELECT curves fit to the proportion of the total catch in the commercial dredge relative to the total catch (survey and commercial) for 2011 cruise to the NYB. Bottom Panel: Deviance residuals for the model fit.



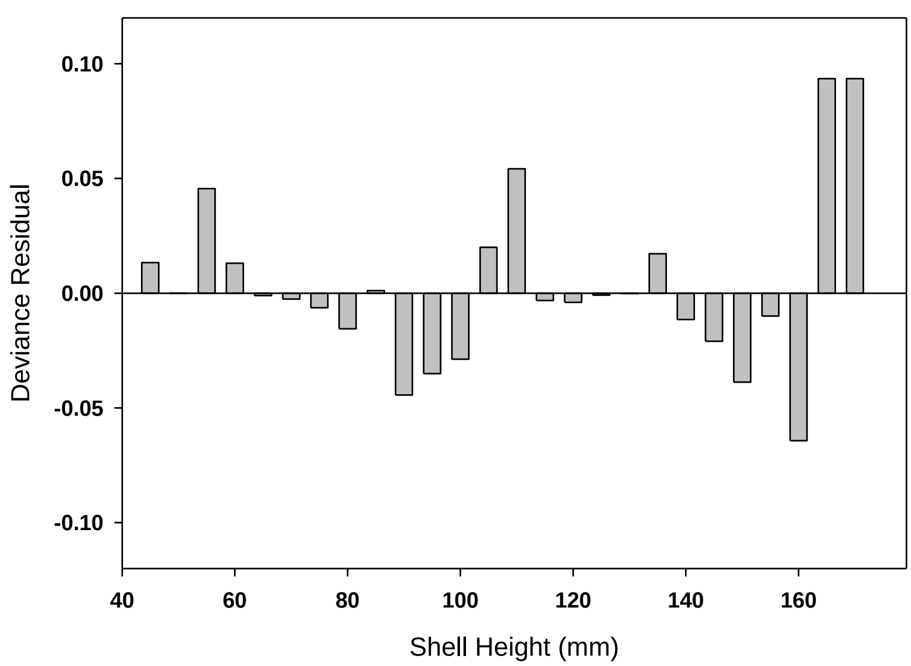


Figure 19 Estimated selectivity curves for the CFTDD based on data from the 2011 surveys of the SNE/LI (top panel) and NYB (bottom panel).

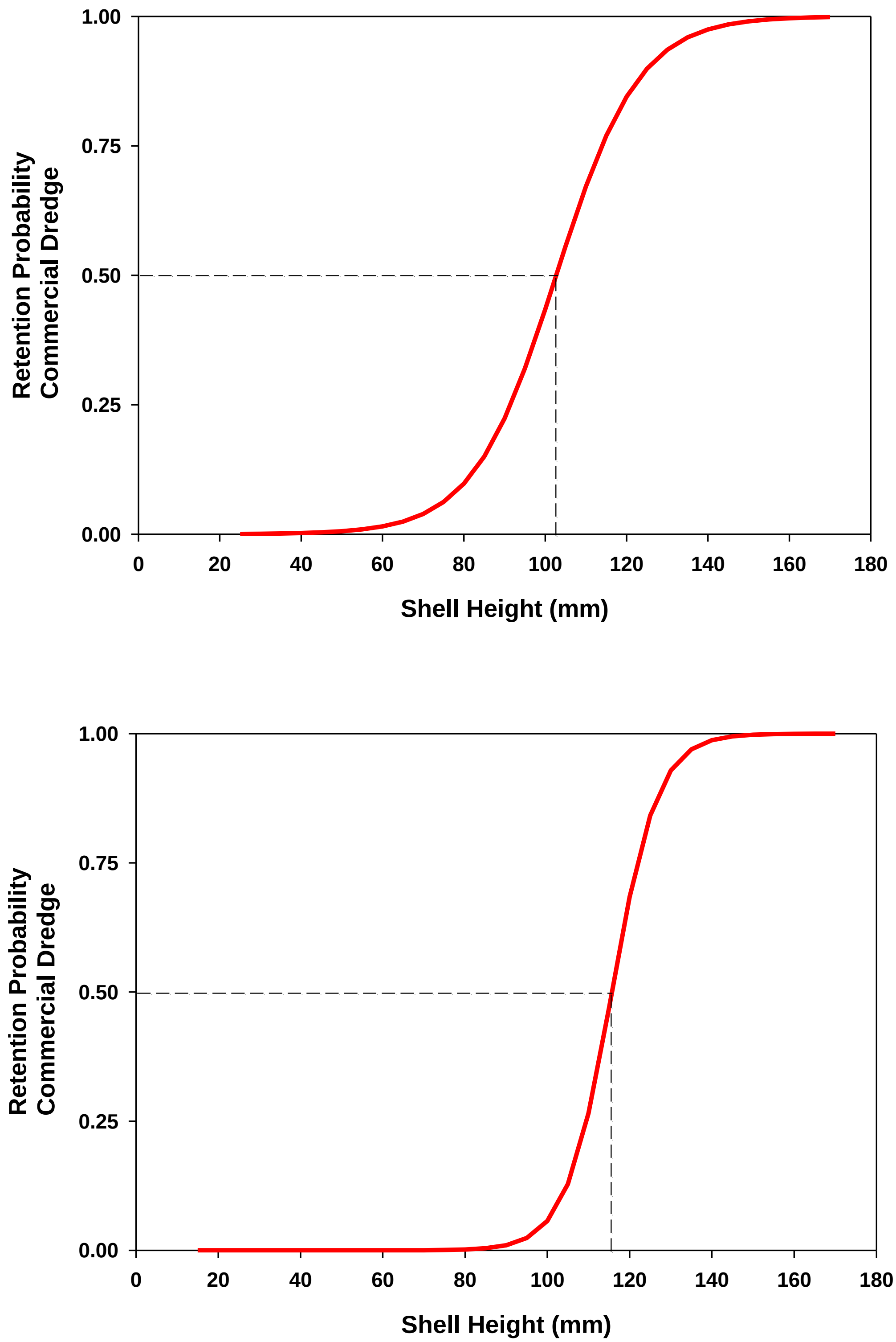


Figure 20 Selectivity parameters (L_{50}, SP and *p*) as a function of percentage of survey dredge filling with sand dollar for tows on both cruises where individual tow model fits could be obtained. Polynomial fits with 95% confidence intervals are shown to depict relationships between the parameters and degree of filling